irc | 2023

SLTC Research University

International Research Conference of SLTC 2023

Conference Proceedings

Fostering Innovation Through Research, Science and Technology

14th & 15th December 2023

Sri Lanka Technology Campus, Sri Lanka

ISBN 978-624-6045-02-9

Published by the Sri Lanka Technology Campus, Colombo, Sri Lanka

Cover Page: Gihan Madusanka, Sri Lanka Technology Campus

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IRC 2023
https://irc2023.sltc.ac.lk

Conference Venue
Colombo, Sri Lanka

Organized By
Sri Lanka Technology Campus

A Message from the Vice Chancellor

I am happy to write a message to the International Research Conference of Sri Lanka Technology Campus – IRC 2023, of the SLTC. It is indeed a great joy to see the interest among the research community increase every year.

Research is "creative and systematic work undertaken to increase the stock of knowledge". Research is what drives humanity forward. It is powered by curiosity: we get curious, ask questions, and engage ourselves in discovering everything there is to know. Learning is flourishing and growing. Without curiosity and research, progress would be slow, and our live as we know it would be wholly different. Research involves the collection, organization and analysis of information to increase understanding of a topic or issue. A research project may be an expansion on past work in the field, to test the validity of instruments, procedures, or experiments, research may reproduce aspects of previous projects or the project as a whole. In all of the above endeavors, research must lead to new applications. Such research is usually carried out by post graduate students and post-doctoral fellows.

It is pleasing to see that undergraduate research too is a component in IRC 2023. Developing and preserving undergraduate research programs benefits students, faculty mentors, and the SLTC Campus. Incorporating a research component along with a sound academic foundation enables students to develop independent critical thinking skills along with oral and written communication skills. As faculty, we believe the research experience is very valuable for students at SLTC. It provides numerous benefits to students and faculty, as described above. However, those who have supervised research projects know it can be a trying or frustrating encounter at times. Therefore, it is particularly pleasing to hear our students speak positively about their research projects carried out at SLTC and undoubtedly they look at their undergraduate experience as a means to not only learn how to perform research, but also to learn problem-solving skills that translate to arenas beyond the classroom or laboratory.

SLTC in turn benefits from presentations and publications that serve to increase its visibility in the scientific community. Whether projects are derived through student-generated or mentor-generated means, students benefit from completion of exposure to the hypothesis-driven scientific method. It is heartening to know that SLTC was ranked 3rd among private universities in Sri Lanka, by International AD rankings, which captures the research and innovation capacity of a higher educational institute.

At a higher level, working on research is overwhelming because students are exposed to opportunities to preview and invent the future. In classes, internships, and most full-time jobs students secure after graduation, students deal with work that will be immediately used in the present or near future. In industry, the main priorities for young employees are to deliver projects with near-term value in the coming week, month, or year.

It is understood that every individual researcher gets to work on only a small, specialized part of a bigger research problem. But just being there and participating is a great opportunity. One of the main purposes of campus life is to expand your intellectual horizons, and hands-on experience in a research lab is a good way to do so. The broader ideas students are be exposed to in a research lab could well transfer over to their future professional lives in unforeseen ways, even if they move on to other areas.

I wish future efforts of research at SLTC a great success.

Professor Veranja Karunaratne
Vice Chancellor
SLTC

A Message from the General Chair

Dear Esteemed Colleagues and Distinguished Participants,

It is with great pleasure and honor that I extend my warmest greetings to all of you as the Chair of the International Research Conference 2023, organized by the Sri Lanka Technology Campus (SLTC).

In the pursuit of advancing knowledge, fostering innovation, and promoting collaborative research, our conference serves as a nexus for scholars, researchers, and industry experts from around the globe. This gathering is a testament to our shared commitment to the pursuit of excellence in academia and beyond.

Throughout the conference, we will have the opportunity to engage in insightful discussions, exchange groundbreaking ideas, and form meaningful connections that transcend geographical boundaries. The diverse range of topics and perspectives presented here reflects the richness of our collective intellectual endeavors.

I would like to express my deepest gratitude to the Vice Chancellor, SLTC Management, organizing committee, keynote speakers, and all participants for their invaluable contributions in making this event a reality. Your dedication to the advancement of research and education is truly commendable.

As we embark on this intellectual journey, let us embrace the spirit of collaboration and discovery. May the interactions during this conference inspire new avenues of research, fostering a lasting impact on our respective fields.

Thank you for being part of this academic celebration. I wish you all a rewarding and enriching experience at the International Research Conference 2023.

Dr. Chamod Hettiarachchi
Chair, International Research Conference 2023
Sri Lanka Technology Campus (SLTC)

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Keynotes on Thursday 14th December 2023

Prof. Rangika Halwathura

Department of Civil Engineering, Faculty of Engineering
University of Moratuwa, Sri Lanka.

Keynote Title: Nature Inspired Solutions (NIS)

Keynote Abstract

More the technology, more the complexity people relish every day. Further, the more we try new things, the more we threaten nature and the environment. The term sustainability has applied in the field and yet to do a post-mortem and reveal to check whether it has applied in the same way as it was defined. The world population increases beyond what it can bear and in addition, their needs are more sophisticated. Furthermore, modern science is trying to use all its powers to solve these sophistications within its ability, leading to many sophisticated solutions. Even within these sophisticated solutions, again the science will be used to find the best out of all. That's where the modern world has mistaken the whole good concept of sustainability, more than it was mistaken, it's more a misuse of the great concept for our own short term goals. However, this whole practice is questionable and needs to adjust soon. Unless it will lead to irreversible damage to the present and to the future. the world should move; new things should be found. New knowledge should be surfaced. That makes the world progress. However, the origin of this matters to define its sustainability. There are enough examples from history in every field that they were inspired by nature for the technology which they have used. From construction to agriculture to medicine to any field of study, the seed and the inspiration was mainly from nature and that made it more sustainable as well as matched the needs of the society while doing the minimum harm to nature. The Nature Inspired Solutions (NIS) is Undoubtedly the future of science and inventions in the future. From history to today, there are many cutting edge technologies, which were real breakthroughs, and which were initiated from nature, however, for us to feel the real sense of nature, we need to escape from the technological trap which we are in today. Hence, it's high time for us to go back to the human mode from the auto mode, so within the complexity, the nature will mould you in such a way to stay away from the complexity, find the solutions either natural or near natural way and have a happy life with the minimum harm to the nature while keeping a better space for the future to plan their life as they wish.

Bio Information

Professor Rangika Halwathura, an esteemed academic and researcher in the Department of Civil Engineering at the University of Moratuwa, possesses a wealth of expertise, knowledge, and experience across various domains. His extensive proficiency extends from sustainable materials and design, green technology, and construction management to structural designing, project planning and monitoring, computer-aided server-based project planning and monitoring, forensic engineering, and Building Information Modeling (BIM).

From April 2019 to August 2021, Professor Halwathura held the position of Commissioner at the Sri Lanka Inventors Commission, demonstrating his unwavering commitment to innovation and progress. His visionary contributions during this tenure have significantly influenced the landscape of invention and creativity.

Internationally recognized, Professor Halwathura serves as a Visiting Professor at the prestigious Peter the Great St. Petersburg Polytechnic University in Russia, contributing to global cooperation and the exchange of cutting-edge knowledge.

Further exemplifying his eminence, Professor Halwathura chairs the Advisory Committee to the Urban Settlement and Development Authority under the Ministry of Urban Development and Housing.

With an impressive scholarly portfolio, Professor Halwathura has authored 56 peer-reviewed journal publications, two books, one book chapter, and presented 125 abstracts and extended abstracts in conference proceedings.

His significant contributions to innovation and intellectual property include 15 national and international patents and three industrial designs. Notably, he holds a prestigious Patent Cooperation Treaty (PCT) patent.

In recognition of his expertise, Professor Halwathura has been invited to various events and conferences as a keynote speaker, guest speaker, and resource person.

Beyond his individual accomplishments, Professor Halwathura has demonstrated a commitment to mentorship, providing exemplary guidance to nearly 80 master's and Ph.D. students, showcasing his dedication to academic leadership.

Keynotes on Friday 15th December 2023

Professor Meththika Vithanage

Ecosphere Resilience Research Center, Faculty of Applied Sciences, University of Sri Jayewardenepura, Sri Lanka
The UWA Institute of Agriculture, University of Western Australia, Australia Sustainability Cluster, University of Petroleum and Energy Studies, Dehradun, India

Keynote Title: Biochar: Cultivating Innovation at the Intersection of Science, Research, and Technology

Keynote Abstract:

Biochar, an organic matter derived from biomass pyrolysis, is a game-changing catalyst that fosters innovation across multiple disciplines by combining science, research, and technology. With its porous structure and unique features, this carbon-rich material offers a path to dramatic breakthroughs in agriculture, environmental sustainability, and renewable energy. Its use as a soil additive improves soil health, increases nutrient retention, and reduces greenhouse gas emissions. Furthermore, the role of biochar in carbon sequestration is a possible alternative in the fight against climate change. Biochar is used as an alternative to activated carbon in wastewater and water treatment due to its universal nature in remediating emerging contaminants, however, the capacity needs to be improved. Moreover, biochar gained its attention as a material from waste conversion. Biochar, as an innovative construction resource, blends smoothly with concrete, increasing its strength, durability, and sustainability while lowering carbon footprints. Biochar's conductivity and porosity promote developments in capacitors, resulting in high-performance and environmentally beneficial solutions. Furthermore, the advent of nano-biochar opens a new horizon for biochar nanostructures to be used in cutting-edge biomedical and environmental applications. This abstract digs into biochar's increasing horizons, charting its progression from soil amendment to a key substance in construction, electronics, and nanotechnology. Biochar is a revolutionary force pushing innovation, supporting scientific curiosity, and accelerating technology discoveries toward a sustainable and resilient future through interdisciplinary collaborations and tireless research.

Bio Information:

Dr. Vithanage is a full professor at the Office of the Dean, Faculty of Applied Sciences, University of Sri Jayewardenepura, Sri Lanka. She is the founding Director of the Ecosphere Resilience Research Centre, University of Sri Jayewardenepura. She is a Young Affiliate of the Third World Academy of Sciences and she became the Chairperson of the Young Scientists Forum in 2017.

She was awarded as the Best Young Scientist, 2018 by the Young Scientist Forum of the National Science and Technology Commission, Sri Lanka and in 2016 she became the Young Scientist in Chemistry by the National Science Foundation of Sri Lanka. She was selected as one of the Early Career Women Scientists by the Organization for Women Scientists in the Developing Countries, Italy. She served as the Chairperson of the Section for Engineering, Architecture and Surveying of the Sri Lanka Association for the Advancement of Science, Sri Lanka in 2018. She has received Presidential Awards for Scientific Publications for 10 years. Prof. Vithanage was awarded as the Best Performing Scientist for few years at the National Institute of Fundamental Studies.

Further, Prof. Meththika Vithanage is considered listed as the top most scientist in Sri Lanka for the Environmental Science based on the scientific output in the International scientific publishing website SCIVal. She has contributed over 125 Science Citation Indexed journal articles, over 30 book chapters and 4 co-edited books published by Elsevier Inc. Her citation record is over to 4800 with an H index of 32. She is not only a scientist, but also a science writer. Her contribution to the newspaper articles exceed 100. She additionally contributed to 2 Korean patents for environmental remediation of antibiotics using biochar. She has served in many national and international scientific committees to promote science.

Keynotes on Friday 15th December 2023

Dr. Karl O. Jones

CEng BEng MInstMC MIET MIEEE FHEA

Keynote Title: Audio and Video Forensics: A New Area For Research and Teaching

Keynote Abstract:

The SLTC Research University is honored to host a distinguished keynote speaker at the upcoming IRC 2023 Conference, representing Liverpool John Moores University. The speaker, an expert in the field of audio and video forensics, will delve into the compelling realm of this critical discipline, shedding light on its pivotal role in contemporary investigations.

The keynote address will feature insightful case studies, emphasizing the significance of audio and video forensics in solving real-world challenges. Through engaging narratives, the speaker will illustrate the invaluable contributions of this field to unraveling complex scenarios, emphasizing why it deserves recognition as a new degree program.

Furthermore, the speaker will unravel the vast opportunities awaiting students and professionals in the realm of audio and video forensics. Drawing from the experiences at Liverpool John Moores University, the keynote will highlight the university's successful collaborations with both state and non-state organizations. These partnerships underscore the commitment to cutting-edge research, showcasing the practical applications and relevance of audio and video forensics in various sectors.

Attendees can anticipate a comprehensive exploration of the collaborative efforts undertaken by Liverpool John Moores University, offering a glimpse into the diverse projects and initiatives aimed at advancing the understanding and application of audio and video forensics. This keynote address promises to be an enriching session, providing valuable insights into the field's importance, potential, and the exciting prospects it holds for academic and professional pursuits.

Bio Information:

Dr. Karl Jones is a distinguished academic currently affiliated with Liverpool John Moores University, where he serves as a Principal Lecturer in the School of Engineering within the Faculty of Engineering and Technology. Proficient in Welsh, Dr. Jones earned his BEng (Hons) in Electrical and Electronic Engineering from Liverpool Polytechnic in 1988. He furthered his academic journey by completing his Ph.D. at Liverpool John Moores University from 1988 to 1991, establishing a strong foundation in his field.

Committed to the advancement of higher education, Dr. Jones earned a Postgraduate Certificate in Teaching and Learning in Higher Education from Liverpool John Moores University in 2001, reflecting his dedication to enhancing pedagogical practices. With an illustrious career at the university since 1995, Dr. Karl Jones's enduring commitment to academia, combined with his leadership position in the School of Engineering, highlights his significant contributions to the field of Electrical and Electronic Engineering. His expertise and dedication make him a respected figure in both education and research.

Table of Content

Full Papers

Posters

EXTENDED ABSTRACT

2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

The Influence of Fines Content on Compaction Characteristics of Poorly-Graded Sands

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***Abstract*—In civil engineering, soil compaction refers to the process of raising soil density by reducing the volume of voids or air spaces inside it. This is done to improve the soil's engineering properties, making it more stable and capable of bearing heavy loads. Compacted soils are common foundation materials for buildings, roads, embankments and other infrastructure projects. Most construction projects use sand as a filling or foundation material because of its cost-effectiveness. But pure sand is difficult to get good compaction because sand grains are not sensitive to the compaction that causes their strong structure. According to previous researchers, the maximum dry density can be increased and the optimum moisture content can be decreased by increasing the fine content of sands. This means that increasing the fines percentage helps reach the densest state with the least water content. However, previous researchers have used fines that were sieved from the original sandy soil in the tests they performed. Hence, this research was focused on observing the variation of compaction characteristics by mixing a natural clay soil at different percentages and performing standard proctor tests in the laboratory. According to the standard proctor compaction test results, increasing the fines content increased both the maximum dry density and the optimum moisture content. But both the measured parameters were observed to have a decreasing trend for fine percentages beyond 15%.**

Keywords—Compaction characteristics, maximum dry density, optimum moisture content, standard proctor compaction test

I. INTRODUCTION

Compaction is a widely used simple ground improvement technique in the construction field. Soil will compact naturally by itself but the main purpose of the compaction is to get the required maximum dry density of soil quickly. It also improves the soil properties, reducing or preventing settlement, increasing soil strength, improving bearing capacity, controlling volume changes and also lowers the permeability. There are different methods that can be used for compact soil such as impact-sharp blow, pressure static weight, vibration shaking, kneading manipulation or re-arranging and different machineries are available such as sheep foot rollers, temping rollers, smooth-drum vibratory soil compactors, pad-vibratory soil compacters and pneumatic-tired rollers etc.

However, the variation of compaction characteristics depends on the soil types, and therefore, the methods and machines that should be used for soil compaction at the site will be varied. Furthermore, doing laboratory testing for compaction will help to study the effect of soil type on compaction characteristics [1]. There are two laboratory tests for compaction: standard and modified proctor compaction tests. According to ASTM D698 and AASHTO T99, for standard Proctor, the hammer weight is 5.5lb (2.5kg) and the drop height is 12 inches (305mm). According to ASTM D1557 and AASHTO T180-D, the modified Proctor method uses a 10 lb. (4.5kg) hammer with an 18-inch (457 mm) drop height for compaction. Therefore, the compaction energy that is applied by the modified proctor test is higher than the standard proctor test. However, based on a past research study, the correlation between maximum dry density and optimum moisture contents is unique for both proctor and modified proctor energy levels. [2]

If we collect a sand sample, it naturally contains some fines. Those fines can go through the voids and fill the voids effectively when compacting the soil sample. Also, water should be added to compact soil because it reduces the frictional force between soil grains. But soils will bounce back if we add more water content. According to past findings, an increase in the fines percentage increases the maximum dry density and requires less water content to reach the densest stage because the voids fill with fines and the volume of the voids decreases. Also, with an increase in fines, the optimum moisture content decreases because the voids to fill with water will decrease [3]. According to the Atterberg limit, fines can be categorized as plastic or non-plastic. Plastic fines give a higher percentage increase in maximum dry unit weight as compared to non-plastic fines [4]. Moreover, their experiment results show the percentage increase in maximum dry unit weight for plastic fines was more than twice that of non-plastic fines.

If the soil properties of sand can be improved by combining it with another type of soil, it will be beneficial for the whole construction process. However, either dynamic compaction or vibro-compaction should be used at the construction site for compacting sandy soils, and both of these methods involve high costs. If we can improve compaction characteristics by adding a proper content of fines, it will become more efficient to select the ideal sandy soil when selecting filling material for the construction. Therefore, it is needed to establish a relationship between the compaction characteristics of sands with different fine contents In this research, the variation of compaction characteristics of poorly graded sands with different fine contents will be discussed, the relationship between maximum dry density and optimum moisture content with different fine contents will be developed and finally, the

effectiveness of fine content for sandy soils for proper compaction in the construction industry will be assessed.

II. Materials and Methods

A sandy soil sample was collected from a location in Meepe, Sri Lanka. Natural clay samples were collected from a paddy field located in Mirigama, Sri Lanka. Both the sandy soil sample and the clayey soil sample were dried for 24 hours at 100°C. Then, a sieve analysis test was done on the sandy soil sample to determine whether it was poorly graded or well graded. After clarifying the type of sandy soil, the entire sample was sieved to separate the sand grains by collecting the sand sieved in between the 4.75 mm and 0.075 mm sieves. Also, the oven-dried clay sample was crushed and sieved from the 0.075-mm sieve to separate pure fines. Then, after mixing 0%, 5%, 10%, 15% and 20% of clay soil into the sand, 25 standard proctor compaction tests were done for the sand sample according to ASTM D698. Finally, the moisture content and dry density values were measured to determine the relationship between them.

III. Results and Discussion

A. Sieve Analysis Test

Figure 1 shows the grain size distribution curve of the sandy soil sample taken for the experiment. This graph was used to determine the 10% passing (D_{10}), 30% passing (D_{30}) and 60% passing (D_{60}) grain sizes. Then the coefficient of uniformity (C_u) and the coefficient of curvature (C_c) were calculated.

The following equations (1) and (2) were used to find the values of C_u and C_c.

$$C_u = \frac{D_{60}}{D_{10}} \quad (1)$$

$$C_c = \frac{D_{30}^2}{D_{10}D_{60}} \quad (2)$$

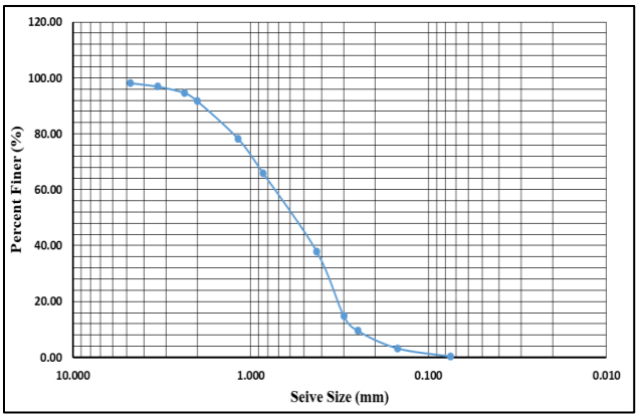

Fig. 1. Grain size distribution curve for sandy soil sample

The below Tab. 1 shows the values that were taken for the classification of the above sandy soil sample.

TABLE I. Important Values of Soil Classification for Sandy Soil Sample

Gravel %	1.98
Sand %	97.82
Fines %	0.29
D_{10}	0.255 mm
D_{30}	0.383 mm
D_{60}	0.762 mm
C_u	2.988
C_c	0.755
SG	2.6548

According to the Unified Soil Classification System (USCS), this sandy soil sample is a poorly graded sand.

B. Standard Proctor Compaction Test

Below Fig.2 illustrates the five compaction curves corresponding to the tests performed on the soil samples that were prepared by mixing different percentages of clay.

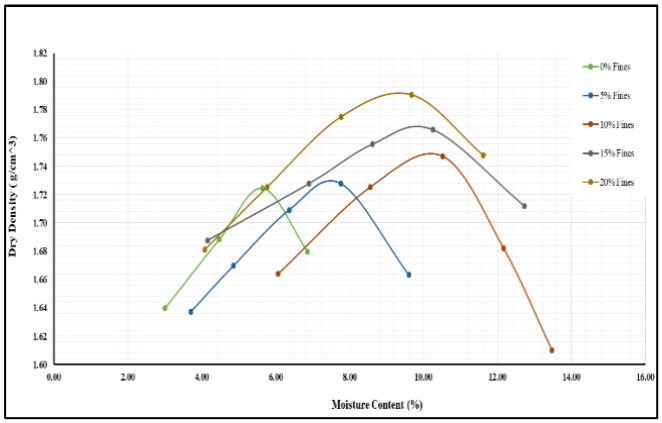

Fig. 2. Compaction curves for the sand sample

Figure 3 shows the variation of maximum dry density (MDD) with different percentages of clay content. The graph reveals that, the maximum dry density increases proportionally with the clay content.

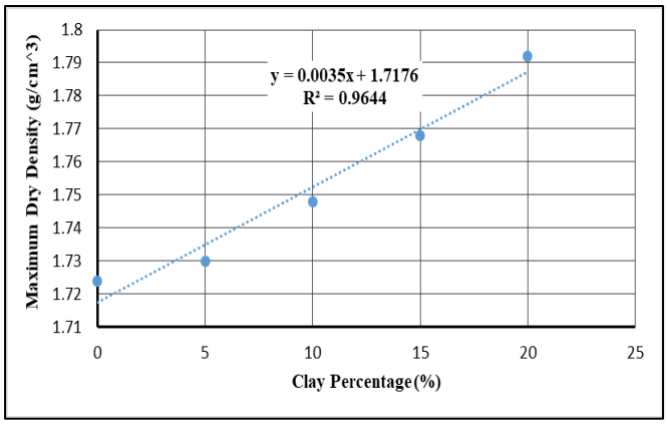

Fig. 3. The variation of MDD with different clay percentages

According to above figure, the relationship between the maximum dry density and clay percentage can be derived as a linear equation and the maximum dry density at 0% clay

content, reads as $1.7176\,g/cm^3$. The gradient of the line represents the increase of the MDD corresponding to the increase of the clay percentage.

Figure 4 shows the variation of optimum moisture content (OMC) with increasing percentages clay content.

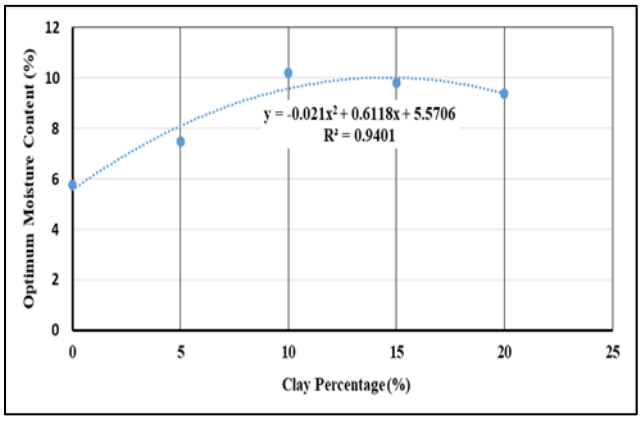

Fig. 4. The variation of OMC with different clay percentages

According to the above graph (Fig. 4), the optimum moisture content increases with the clay percentage up to a certain level and then commences a downward slope. The best fitting curve for the plotted data gives a 2nd degree polynomial with a R^2 value of 0.9401 (Equation 3), y being the OMC and x being the clay percentage.

$$y = -0.021x^2 + 0.6118x + 5.5706 \quad (3)$$

Hence, the clay percentage that gives the highest OMC, was derived (Equation 4 and 5) as 14.5667%.

$$\frac{dy}{dx} = -0.042x + 0.6118 = 0 \quad (4)$$

$$x = 14.5667 \quad (5)$$

IV. Conclusion

Based on the above standard Proctor test results, increasing the natural clay content caused an increase in maximum dry density because the voids were filled by fines going through the sand grains (refer figure 3). The main observation that can be seen in Figure 4 is that the moisture content increases until the added percentage of clay is at 14.5667% (refer equation 5) since the frictional forces between soil grains are reduced due to the water filling the voids. Then it starts to decrease when adding clay percentages beyond 14.5667%. This is due to the filling of voids by fines, causing to reduce the frictional forces and voids by adding more fines. Therefore, this helps to understand that the increased clay content of sandy soil is ideal for achieving better compaction with less water content. But the above equations, derived from the graphs shown in figures 3 and 4, are limited to poorly graded sands. Therefore, future development should be done for the well-graded sand.

Acknowledgment

The authors declare that no fund was received for this research.

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2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

A TENG Energy Harvesting System with HV Limiting Technique Using Zener Diodes and Impedance Tracking MPPT

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***Abstract*—This document is a Zener diode-limited high voltage (HV) buck converter energy harvesting system for triboelectric nanogenerator (TENG). The TENG commonly generates HV around 100 V. It is impossible to connect directly to switches. However, the proposed system can harvest energy from a wide voltage range of TENG. A long charging time induces wasting energy if it uses a fractional open-circuit voltage (FOCV) to obtain power higher than the breakdown voltage. We propose impedance tracking maximum power point tracking (MPPT), which adjusts the effective impedance of the converter using the pulse-width modulation (PWM) method. We present low-power zero-current sensing (ZCS) based on a common-gate comparator to prevent flowing reverse current from the output stage. The proposed system is designed on a 180-nm bipolar-cmos-dmos (BCD) process. The 40 V Zener-diode array and the highest breakdown voltage of MOSFET in this process are used for utilizing a high voltage input around 100 V. The measured peak conversion efficiency of 89.7 % is achieved for delivering an output power of 1.25 mW.**

Keywords—High voltage buck converter, TENG, MPPT, zero-current sensing

I. INTRODUCTION

With the miniaturization of various electronic devices, portability with convenience has been emphasized [1]. The portability is closely related to the charging and sustaining of power to ensure correct functional operation. Therefore, interest in energy harvesting from ambient has increased. The triboelectric nanogenerator (TENG) [2] is useful for miniaturizing and is suitable for application to the low-frequency motion of the human body. Furthermore, it has a higher energy density than a piezoelectric generator (PEG) [3]. However, the main challenge of TENG as an energy harvesting source is that the TENG usually generates a high voltage (> 100 V) with a high internal impedance (~ MΩ). When the high voltage is applied directly, the inside of the chip can be destroyed. Also, implementing an efficient energy extraction technique is difficult for matching high impedance.

Therefore, this paper proposes a Zener diode-limited high-voltage buck converter to maximize the input power rather than stop the converter operation. The proposed converter uses Zener diodes to extract power and protect the chip. In this 180-nm BCD process, the MOSFETs with a 40 V breakdown voltage cover the high voltage. For 40 V of source input, the converter uses the same power as when it samples 40V for 80 V input voltage without wasting energy with sampling time.

II. PROPOSED ARCHITECTURE

Fig. 1(a) shows the architecture of the proposed diode-limited high-voltage buck converter. It comprises an input source including TENG with a full bridge rectifier (FBR), a 40 V Zener-diode array (V_Z), two power switches for buck operation (M_P and M_N), and an inductor. A load resistor (R_L), an input capacitor (C_{IN}), and an inductor (L) are off-chip components. The C_{IN} and on-chip FBR offer smooth source voltage of AC voltage from TENG. The 40 V Zener array limits V_{IN} to prevent the breakdown of M_P.

Fig. 1(b) shows the block diagram of the system controller, which generates $\Phi_{P,HV}$ and $\Phi_{N,M}$ for M_P and M_N, respectively. It consists of a voltage sensing block, an MPPT block, a zero-current sensing (ZCS) block, and two-level shifters (LS). The voltage sensing block tracks V_{IN} and produces low voltage (V_{sen}). Using V_{mpp} and V_{sen}, the MPPT block generates $\Phi_{P,LV}$. The ZCS block generates Φ_N based on c for controlling M_N. Two level shifters use different supply voltages: Low-LS makes $\Phi_{P,LV}$ increases from V_{DD} to V_m, and High-LS increases the output of Low-LS from V_m to V_{IN}. V_{DD} (=1.8 V) is for logic gates in MPPT and ZCS, V_m (=5 V) is for middle voltage, and V_{IN} is for keeping off-state of M_P.

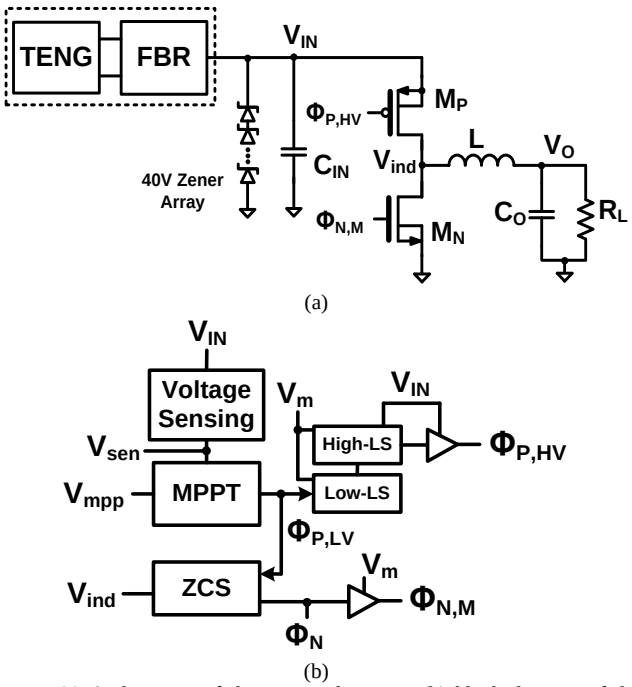


Fig. 1. (a) Architecture of the proposed system, (b) block diagram of the system controller.

Fig. 2 illustrates the operation of the proposed converter ($V_{S/2} > V_Z$). In this case, the average input power ($P_{IN,avg}$) of the converter can be derived as,

$$P_{IN,avg} = \frac{V_Z (V_Z - V_O)}{2L} \cdot f_S \cdot t_{ON}^2 \cdot \quad (1)$$

Where L is the inductance, f_S is the switching frequency of the converter, and t_{ON} is the on-time of M_P. It keeps tracking the maximum power point even though it is impossible to get the exact maximum point (V_{mpp}). The effective input impedance (R_{IN}) can be derived as follows [4],

$$R_{IN} = \frac{2L}{t_{ON}^2 f_S (1-\beta)}, \quad (2)$$

where $\beta = V_O/V_{IN}$. Eq. (2) means that the MPPT controller increases the t_{ON} to decrease the effective input impedance of the converter. Fig. 3 shows the calculated result of $P_{IN,avg}$ as a function of t_{ON} when $P_{IN,max}$ = 500 μW with 100V source voltage. Therefore, the proposed system extends the available power range of TENG.

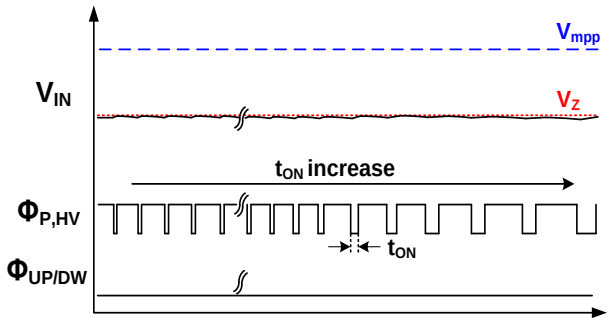


Fig. 2. Operational waveform of the proposed converter. ($V_S/2 = V_{mpp} > V_Z$)

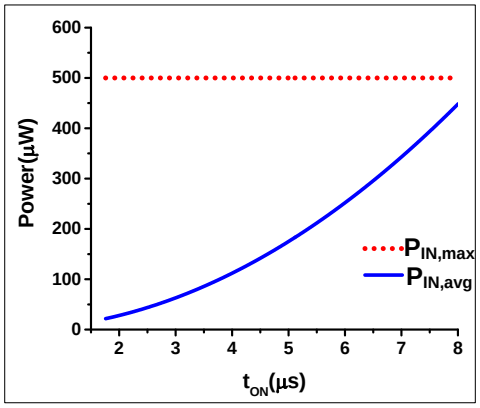


Fig. 3. The calculated result of $P_{IN,avg}$ as a function of t_{ON}.

Fig. 4 shows the block diagram of the ZCS controller. It consists of a common-gate comparator to compare between V_{ind} and ground, M_{N2} for inducing V_{ind} into the comparator, and several logic gates. The ZCS controller is operated when $\Phi_{P,LV}$ is rising edge. Once $\Phi_{P,LV}$ becomes high, Φ_N is high to connect V_{ind} and comparator through M_{N2}. Even though the comparator always operates, it consumes power when M_{N2} is turned on. Therefore, the ZCS controller consumes only 160 nW. Fig. 5 shows the simulated waveform of the ZCS controller. The delay prevents the shoot-through current, generating a short circuit when M_P and M_N are turned on simultaneously.

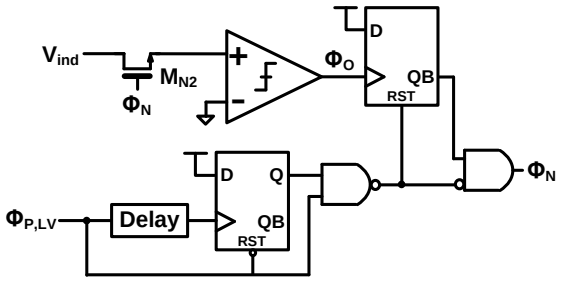


Fig. 4. The block diagram of the ZCS controller.

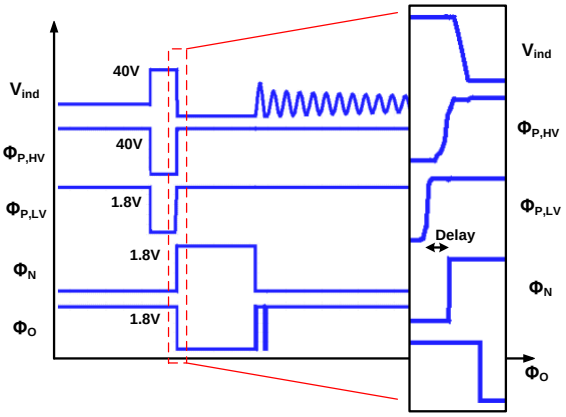
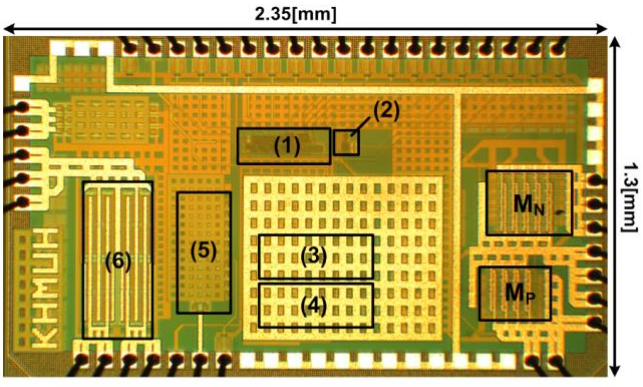


Fig. 5. Simulated waveform of ZCS controller in steady state.

III. Experiment Result

The converter IC has been fabricated on a 180-nm BCD process. Fig. 6 shows the chip micrograph with an area of 3.055 mm^2. Table I shows a performance comparison with the state of the arts. All designs are fabricated using the BCD process supporting high voltage. Each process has its limit voltage: works [5],[6], and [8] have 70 V, work [7] has 60 V, and our work has 40 V. However, the maximum input voltage of works [5],[6], and [7] are saturated up to their limit voltage. On the other hand, work [8] and our work achieve harvest above the limit voltage. Even though work [8] makes the power possible to extract almost two times the limit voltage, it uses a multi-chip stacking technique, which increases the system's volume. Lastly, our work obtains 89.7 % conversion efficiency at output power (P_{OUT}) = 1.25 mW, comparable to the result of [8], which shows 70.7 % conversion efficiency when the P_{OUT} delivers 1.2 mW.



(1) MPPT controller
(2) ZCS controller
(3) Level shifter (1.8V - 5V)
(4) Level shifter (5V - V_{in})
(5) High voltage sensor
(6) Full bridge rectifier

M_N = 4500 μm / 3.5 μm
M_P = 4800 μm / 2 μm

Fig. 6. Micrograph of the fabricated IC

TABLE I. PERFORMANCE COMPARISON

	[5]	[6]	[7]	[8]	This work
Process	180 nm HV BCD	180 nm HV BCD	250 nm HV BCD	180 nm HV BCD	180 nm HV BCD
Energy source	TENG	TENG	TENG	TENG	TENG
Type	Rectifier, Buck,[1]SC	Rectifier, Buck	Rectifier, Buck	[2]MCS-BF	Rectifier,Buck
MPPT technique	p-SSHI	FOCV	2-D MPPT	-	Adaptive PWM
Inductor	1 mH	1 mH	10 mH	10 mH	20 mH
V_{OUT}	2 V	2 - 5 V	0 - 5 V	3.1 - 4.3 V	2 - 5 V
η_{CONV}	32.71% @ P_{OUT} = 722 µW	54.48% @ P_{OUT} = 20.7 µW	85% @ P_{OUT} = N/A	70.7% @ P_{OUT} = 1.2 mW	89.7% @ P_{OUT} = 1.25 mW
Area	6.25 mm^2	2.482 mm^2	3 mm^2	N/A	3.055 mm^2
Limit Voltage	70 V	70 V	60 V	70 V	40 V
Maximum Input Voltage	70 V	70 V	60 V	> 135 V	> 40 V

[1]SC : Switched Capacitor [2]MCS-BF : Multi-Chip-Stacked Bias-Flip

IV. CONCLUSION

A rectifier (FBR) is required to shape AC voltage from the input source (TENG) to realize the proposed model. The converter IC is implemented using a 180-nm HV BCD process in an area of 3.055 mm^2. The process has a limit voltage of 40 V, which is the breakdown voltage of high-voltage transistors. To avoid power loss from sampling, the converter uses adaptive pulse width modulation (PWM), increasing harvested input power. In addition, we use a Zener-diode array to clip the voltage to protect devices and to harvest more power above 40 V of input voltage. In measurement, a peak conversion efficiency of 89.7 % is achieved for delivering an output power of 1.25 mW.

ACKNOWLEDGMENT

This chip fabrication was supported by the IC Design Education Center (IDEC), Korea.

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2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

Design and Analysis of Rotational Machinery System for Harnessing Vehicle Vibrations on Roadways for Energy Harvesting Applications

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***Abstract*—Energy is a fundamental determinant of our quality of life, and our modern lifestyle depends heavily on it, yet the resources used for generating it are depleting rapidly, leading to an energy crisis. The vitality of this arises as fossil fuels are being overconsumed, which makes it challenging to provide sufficient power in the next era as an effect of a growing population. To address this issue, numerous research work is being conducted on renewable energy sources. However, certain unconventional methods, such as renewable energy formed from objects in motion, various vibrating machines or any other source of mechanical energy have yet to be fully explored. Hence, this source of energy is dispersed and thus wasted.**
In response to this challenge, we have developed an innovative energy harvesting system, designed to capture energy from moving vehicles as they move on roadways, particularly when passing over speed bumps. Our approach mitigates some of the significant limitations found in earlier systems and presents novel solutions to these issues. Remarkably, the system can achieve 720 J energy with only 66 passing vehicles, providing an efficient means of energy storage. The system will be able to store power which could be used for street lighting in both urban and rural areas, road signs, and various other essential road-related devices. This abstract outlines the development of this energy harvesting system, its applications, and its significant potential to transform the energy landscape.

Keywords—Energy harvesting, mechanical, converter, gear wheel

I. INTRODUCTION

A. Background and Significance

One of the most important resources that determine the quality of life is energy. The search for a new energy source has been a key problem for today's civilization, given the limited fossil energy available for the next century [1]. Oil, gas, and coal may continue to exist for the next several decades [2] . To meet the expected energy demand as the population rises and to sustain economic growth, alternative forms of energy such as renewable energy needs to be expanded [3]

The term Energy Harvesting or Renewable Energy, is a method of producing electrical energy by utilizing the energy surrounding the environment from the sun and wind, for example. [4] Energy harvesting techniques are emerging as environmentally friendly energy sources, which form a promising alternative to existing energy resources [5]

However, apart from the various known methods, renewable energy formed from various vibration machines, objects in motion, or any other source of mechanical energy is not being captured. Therefore, this source of energy is dispersed and thus wasted. [4]. In this sense, numerous researchers are working on technologies for renewable energy harvesting and exploring increasing the energy harvesting efficiency of the energy harvester system. [6]

A large amount of kinetic energy is wasted in the form of friction and heat when vehicles pass over the speed bumps and it can be converted into electrical energy in different ways [7]. On the road, pressure has a wider range of force recovery options. As a result, this technology uses the force generated by road bumps as a new, alternative renewable energy source. [8]

An electromagnetic renewable energy harvesting system is a mechanism of harvesting energy from moving vehicles on the road designed to be installed under the road surface This system uses both mechanical and electrical components to generate electricity.

The project aims to design a sustainable, cost-effective solution for the utilization of waste energy from vehicles passing over a speed bump, which is much relevant and important as the number of vehicles is rapidly increasing day by day. The process is modeled and simulated using a vehicle track force, gear wheels, and the motor to convert rotational energy into electricity, a converter to increase the voltage and a supercapacitor bank with 12V, (720J)

The output is a variable current due to differences in the type of motion, therefore, a full-wave rectifier is used to convert the current, which is alternating in nature to unidirectional D.C current that can be stored and used in multiple ways. The generated power will be stored in a 12V supercapacitor bank, which is practically useful for supplying safety signals, streetlights, automated ticket machines at road bumpers, and other systems on the road, which requires power that the proposed energy-harvesting system has the potential as a renewable alternative energy source.

B. Literature Review

In recent years several research works have been carried out on road-based energy harvesting using different mechanisms. Several review articles, publications, and product prototypes have been published on this topic covering a wide variety of mechanisms and techniques [5]. Within the electronic energy harvesting field, piezoelectric, pyroelectric, and triboelectric energy harvesting have attracted the most research attention.

Piezoelectric materials are widely used to generate energy to power low-energy-consuming equipment. A system was made to generate voltage ranging from 400 to 700 v under a traffic volume of 4000 vehicles per day. using multiple cylindrical piezoelectric elements. The corresponding power output was obtained, yielding a power range between 0.08-2.1 Watts per system. [8]

Another paper has developed an energy harvesting system based on piezoelectric elements embedded into the pavement structure. It involved numerical modeling of the stress distribution in the power generation module and economic analysis of the value of the electric power generated, under a given traffic composition scenario. [9] Subha [4] illustrated the streetlight glowing system on vehicle detecting movement and the functionality of piezoelectricity in roads to utilize energy executed from the moving vehicles. Electromagnetic energy harvesting systems capture energy from subtle structural movements, like vibrations in roads and buildings, by converting kinetic energy into electricity through the interaction of magnets and coils. Numerous studies have explored this method of converting motion into electrical power through electromagnetic induction [10].

Padma Rao developed a system of the rack and ratchet (pinion) mechanism which is used to develop the power from speed breakers with the potential to generate approximately 0.98 kilowatts of power when a 1,000 kg vehicle ascends a 10 cm high speed-breaker [11]. *Jassoja* presented a system by using a sliding plate mechanism aimed at harnessing wasted energy from road tire friction caused by increasing vehicle traffic. This system effectively converts this frictional energy into usable electrical power. [12].

[10] X. Zhang developed a renewable energy harvesting system using a mechanical/track vibration rectifier (MVR) for railroads.

II. Methodology

A. Working Mechanism

In order to regenerate maximum energy, a highly efficient energy conversion mechanism is designed as shown in (Fig.1). The project's core mechanism resides within the road bumper. As a vehicle passes over the speed bump, it imparts a downward force upon the top plate of the system, initiating the energy conversion process.

This force triggers the downward motion of a pinion rack, which is connected to an axial shaft. Two gear wheel systems are parallelly connected in this shaft: one with a higher number of teeth (44) and another gear wheel with a higher ratio, connected to a chain and a driven gear wheel on the opposite side.

In order to maintain a continuous and consistent motion within the mechanism, a flywheel is incorporated. Additionally, a ratchet-type bearing is used to get the pinion's unidirectional motion,

The flywheel serves as an energy reservoir, storing rotational energy to ensure smooth and uninterrupted operation even when vehicles pass intermittently.
The driven wheel, now synchronized with the rotational energy generated from vehicle movement, is directly linked to the motor and outputs an AC voltage. This AC voltage is subsequently converted to DC by an AC-to-DC converter. A boost converter increases the voltage and the increased voltage is sent into supercapacitors and store the energy. In addition, capacitor stored generated voltage status can be measured by an Android phone.

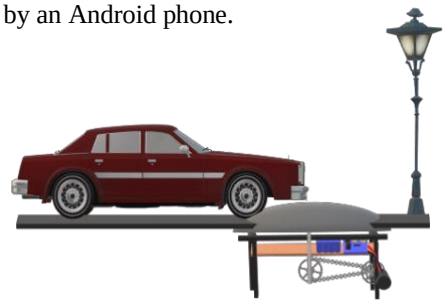


Fig. 1. Project application overview

B. System Design

1) Structure

The upper iron plate is intended for use as both a road surface for vehicles and as a method for regulating their speed while they are on the road. Gear wheels are mechanical devices used to transmit power and motion from one part of a machine to another. The rack and pinion mechanism consists of a linear gear(rack) and a rotating gear (Pinion), which is commonly used to convert rotary motion into linear motion or vice versa, such as in steering systems for vehicles. Rubber rollers help to keep the linearity when the rack and pinion go down. The flywheel acts as an energy reservoir, providing stability, smoothing out variations, and helping to ensure that the system operates consistently and efficiently. Chains in combination with gearwheels are a versatile and reliable means of transmitting power, adjusting speed and direction,

and ensuring robust and efficient mechanical operation in a wide range of applications.

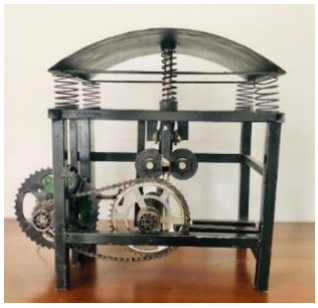
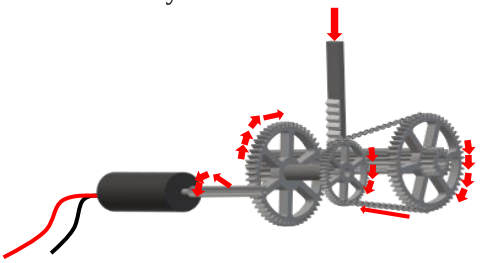


Fig. 2. Structural development

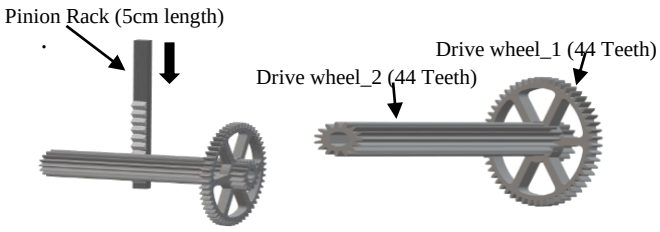
As soon as the car's front wheel passes by the top iron plate, it will recover to its initial position in a short period of time, after its linearly down motion. This is achieved by the springs compatible to weight which doesn't affect the rotation system. Flywheel helps to maintain the same direction to rotate.

2) Gear wheel system

When a vehicle exerts force on the upper plate, it causes the pinion rack to move linearly downwards by a distance of 5 cm. The drive wheels, known as Drive Wheel 1 and Drive Wheel 2, are part of a compound gear wheel system, with both gear wheels rotating in the same direction. Remarkably, as the pinion rack descends by 5cm, the drive wheels complete approximately 0.75 full revolutions. Five types of gear wheels are used in the system in various sizes.

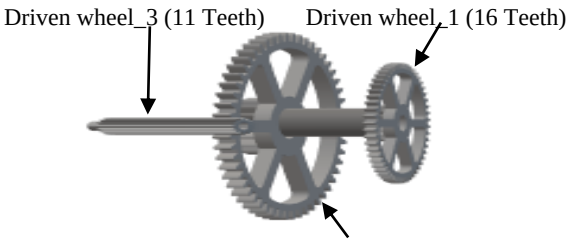


$$Gear\ Ratio = \frac{No.of\ teeth\ of\ Driven\ wheel}{No.of\ teeth\ of\ Drive\ wheel}$$



$$Gear\ Ratio = \frac{(No.of\ teeth\ of\ Driven\ wheel\_1)\ 16}{(No.of\ teeth\ of\ Drive\ wheel\_1)\ 44} = \frac{4}{11}$$

When the Drive wheel completes 4 rotations, the Driven wheel 1 turns 11 times. If the Drive wheel makes just 1 rotation, the Driven wheel 1 rotates about 11/4 times.
When the Drive wheel completes 0.75 rotations, both Driven wheel 1 and Driven wheel 2 turn approximately 2.063 times.
11/4*0.75 = 2.063 rounds



$$Gear\ Ratio = \frac{(No.of\ teeth\ of\ Driven\ wheel\_3)\ 11}{(No.of\ teeth\ of\ Driven\ wheel\_2)\ 110} = \frac{1}{10}$$

When Driven Wheel 2 rotates 1 round it equals 10 rounds in Driven Wheel 2.

When Driven wheels 1 and 2 complete 2 rotations, Driven wheel 3, linked to the motor shaft, turns 20 times. Consequently, a single force on the iron plate causes the motor to rotate 20 times.
The pinion rack's upward motion does not affect motor rotation because the driven wheel is a freewheel that rotates freely in the opposite direction. Despite force release, the system maintains consistent rotation, and upon the release of the vehicle wheel, the spring tension rapidly readjusts to its initial position in preparation for the next wheel/vehicle transition.

3) Circuit Breakdown

When the road bumper mechanism on top of the plate is pressed, the 24V wiper motor turns 20 times. While it turns, it makes 22.8V of electricity in the AC form. To make this power more useful, the electricity is transformed into a 12V DC voltage. This conversion makes the electricity more practical for the device.

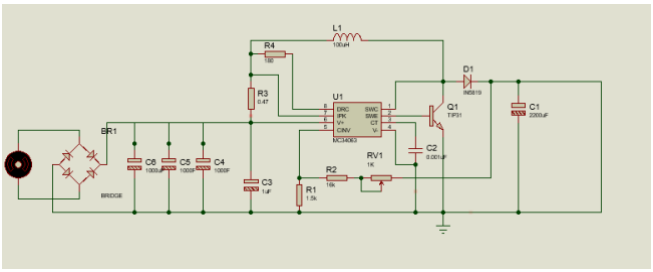


Fig. 3. Schematic diagram of the circuit

AC to DC converter - The circuit is used for converting AC to DC voltage since the 24V wiper motor outputs AC voltage, and a DC voltage is required. Wiper motor was selected due to its high output current and voltage, ensuring optimal performance for achieving a substantial output. This conversion is achieved through an AC-to-DC converter, which includes a bridge rectifier and three 1000µF electrolytic capacitors connected in parallel. As the AC voltage goes through the converter, it rectifies the signal, resulting in a stable 12V output.

Boost converter circuit-The DC voltage from the previous converter, which is at 6.6V, is then boosted to 12V using a boost circuit. The MC34063 special power IC is utilized in this circuit, and it's noteworthy that the MC34063 IC can

handle step-up, step-down, and voltage inverting functions. This circuit operates by energizing and de-energizing an inductor in tandem with the IC's switching component, which is regulated by an external capacitor. The circuit yields an output voltage of 14V within an input voltage range of 3V to 13V. Furthermore, the circuit's efficiency is approximately 65.95%. If an adjustment to the output voltage is necessary, it can be achieved using the following equation by substituting the values of resistors R4 and R3.

$$Vout = 1.25(1 + \frac{R4}{R3})$$

The selection of a 12V (720J) supercapacitor bank for this energy storage device is primarily driven by its considerably lower internal resistance compared to other battery options. Furthermore, supercapacitors are known for their capability to provide exceptionally high output currents when needed, making them a preferred choice for the application.

4) Voltage monitoring

In order to monitor the voltage, the system was further developed with a voltage monitoring system. The charging status is displayed into an android mobile phone using a voltage sensor.

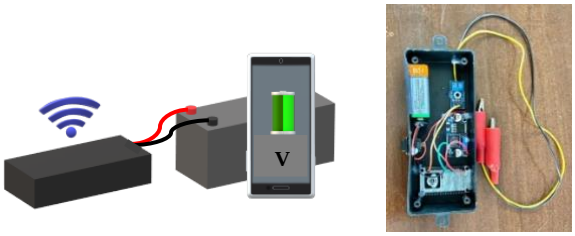


Fig. 4. Voltage monitoring circuit

III. EXPERIMENTED RESULTS

The experimented results of the system reveal that, following experimental procedures, 11 forces generated 1V, while 132 forces provided a substantial 12 volts, equivalent to 720 joules of energy. A single vehicle contributing two forces demonstrated the system's efficiency. In practical terms, the collective effort of 66 vehicles is required to supply the necessary 132 forces, allowing for the complete charging of the 12-volt, 720-joule battery.

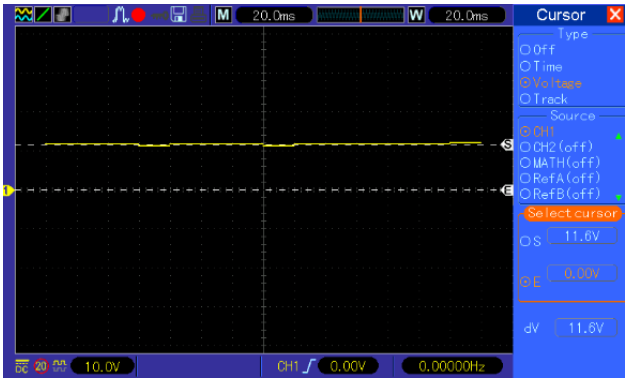


Fig. 5. System performance output

Fig. 6. System performance output with 11.6V

Fig. 7. Energy harvesting system

IV. CONCLUSION

In conclusion, the development of this innovative energy-harvesting system represents a significant step toward addressing the escalating energy crisis and environmental concerns. The results demonstrate the system's ability to capture and store energy effectively, with just 66 passing vehicles (approximately 1900 kg weight car), required to fully charge the 12V super capacitor bank so that it can generate 720 J energy. This holds the potential to revolutionize the way we approach energy generation and consumption, ushering in a cleaner, greener, and more resilient energy future.

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2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

Detergent Aerosol and Electric Field Assisted Low Cost Emission Purifier for Automobiles

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***Abstract*—The increasing levels of air pollution have raised significant concerns about public health and environmental sustainability. On a global scale, air pollution is attributed to approximately 7 million premature deaths annually, 70% of those deaths occur in Asia-Pacific region. Air pollution poses a significant challenge in South Asian countries. WHO database states two major groups of air pollutants particulate matter (PM) and nitrogen oxides (NOx), the main source of them primarily arises from vehicular emissions. Sri Lanka is categorized as a country with a moderate level of air cleanliness with a US Air Quality Index (AQI) of 78. The average annual concentration of the pollutant $PM_{2.5}$ is at 25 µg/m³[1-3]. Among the pollutants emitted by automobiles, microscopic particulate matter (PM) has been identified as a major contributor to respiratory disease and climate changes. This study presents a novel device designed to effectively trap and filter particles emitted from vehicle exhaust. The device incorporates a combination of three main components: cyclone filter, electrostatic barrier and unique purification method using aerosol cleaners. The cyclone filter removes the heavier particles, while aerosols interact with most of the fine PM. Additionally, an electrostatic barrier blocks the bypassing of the remaining contaminated aerosols. The objective of this study was to evaluate the device's performance in terms of pollute particle removal ability with distinct way and hence improve air quality. By focusing on removing PM from vehicle emissions, this approach contributes to the promotion of cleaner and greener transport technologies.**

Keywords—Particulate matter (PM), detergent aerosol, vehicular emission

I. INTRODUCTION

Clean air is indispensable to mankind's wellbeing as well as the planet's sustainability for future generations. The breathable atmosphere has a principal bearing on our respiratory system wellness and our general quality of life. Unfortunately, air contamination has become a worldwide predicament, placing numerous hazards on human health and the environment. The exhausts spewed from cars are accounted to be a major factor amongst many others. The burning of fossil fuels in internal combustion motors generates harmful toxins, such as carbon monoxide, nitrogen oxides, particulate matter, and volatile organic compounds, causing serious adverse health effects and environmental deterioration. With the ever-growing number of vehicles on the roads, the need to devise impactful solutions to reduce car emissions has never been greater.

One of the most concerning pollutants in the atmosphere is particulate matter (PM). Particulate matter refers to tiny solid or liquid particles suspended in the air, varying in size, composition, and origin. It can be generated through natural processes such as dust storms and volcanic eruptions, as well as human activities including industrial processes, combustion of fossil fuels, and transportation.

PM pollution has obtained considerable attention due to its harmful effects on human health. These microscopic particles can enter the respiratory system and penetrate deep into the lungs, causing respiratory and cardiovascular problems. Fine particles, known as $PM_{2.5}$, are of particular concern as they are small enough to reach the lungs and enter the bloodstream directly, potentially leading to systemic health issues. Daily exposure to PM has been linked to increased rates of respiratory diseases, lung cancer, and even premature death. The impact of particulate matter extends beyond human health, affecting the environment as well. Fine particles can contribute to reduced visibility and haze formation and decreasing air quality. Additionally, certain components of particulate matter, such as black carbon, can absorb sunlight and contribute to global warming, influencing climate patterns [7-10].

Smoke purifiers, also known as automotive air purifiers or vehicle emission control systems, are designed to remove pollutants from the exhaust gases emitted by vehicles. These devices utilize various mechanisms to trap and neutralize harmful pollutants, thereby reducing their impact on human health and the environment. Commercially available emission control systems are incorporated with various technologies such as high efficiency particulate air (HEPA) filters, activated carbon filters, and UV-C sterilization to effectively trap and neutralize airborne particles and pollutants. These systems include components like catalytic converters and exhaust gas recirculation (EGR) systems. They work by converting or reducing harmful emissions, such as nitrogen oxides, carbon monoxide (CO), and

hydrocarbons (HC), into less harmful substances. By evaluating the current state of smoke purifier technology, we aim to identify the potential challenges and opportunities for their widespread adoption in the automotive industry [11-15].

II. Methodology

Experimental setup (Figure 01) was composed with a cyclone filter, an electrostatic barrier, aerosol generators and a liquid filter. Cyclone filter was built with galvanized iron (GI) sheet to prevent corrosion. Inlet of the cyclone filter was connected PVC pipe and it was attached to a flexible GI hose. The flexible hose can directly be connected to the tail pipe of the vehicle. Here PVC pipe is acted as high voltage insulator in between the vehicle and purifying unit. The cyclone filter, positioned at the inlet of the device, this initial filtration step aids in reducing the load of coarse particulates entering the subsequent stages of the device.

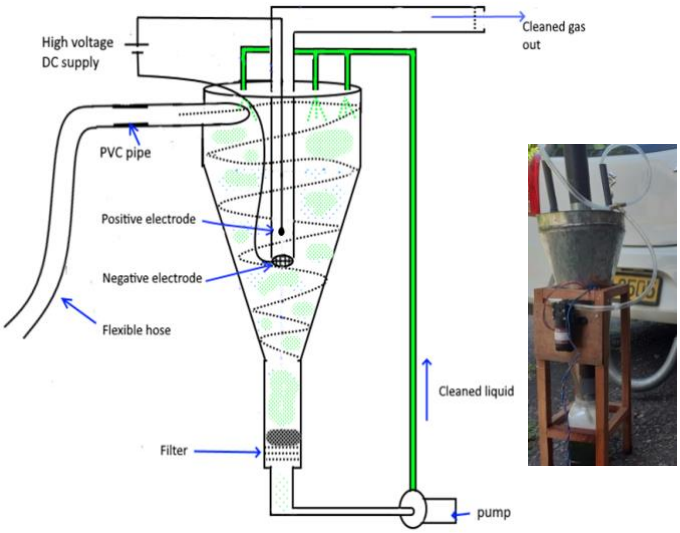

Fig. 1. Experimental setup and a photograph of the emission purifier

A. *Aerosol Generator*

Detergent aerosol generators were built with commercially available low pressure atomizing nozzle and they were fixed inside the cyclone filter and also a cellulose filter was placed at the bottom of the cyclone filter. It was utilized to separate PM from detergent liquid and hence filtrate can be recycled and then it was circulated through the system with aid of mini water pump (12 V 2 A, 3.5 L/min). The flow rate of the cleaned liquid was controlled with motor speed controller (PWM 1803BK Mini DC Motor Speed Regulator 30 W) and therefore the atomization rate of liquid could also be varied. Commercially available dishwasher liquid was diluted with water to get different concentrations of detergent liquid for the experiment.

B. *Electrostatic Barrier*

The Electrostatic barrier was made with two electrodes, negative electrode was iron mesh and an aluminum blind rivet was used as positive point electrode (Figure 02 (b), (c)). The electric field in this configuration exhibits radial symmetry, meaning it extends outwards in a symmetrical pattern from the point electrode towards the negative electrode (Fig. 2). Commercially available high voltage generator module (Fig. 3) was used as high voltage dc source.

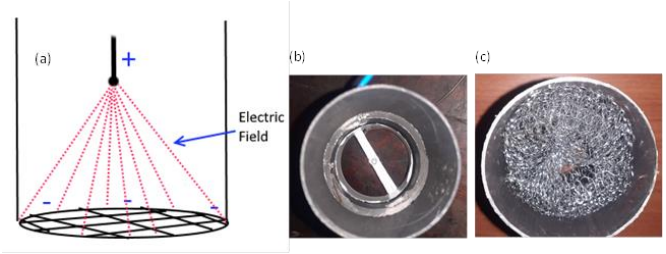

Fig. 2.(a) Electric field, (b) positive electrode and (c) negative electrode of electrostatic barrier

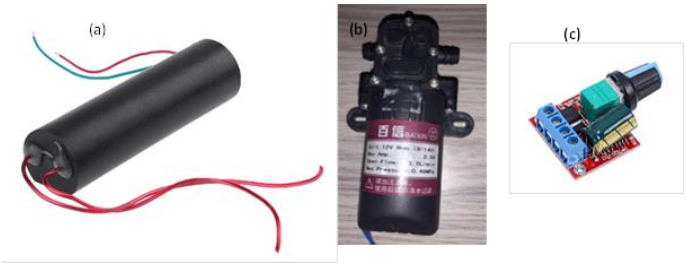

Fig. 3. (a) High voltage module, (b) mini water pump and (C) motor speed controller

Due to the presence of positive and negative electrodes, an electric field is established in the vicinity of the system. When an aerosol droplet passes by the negatively charged electrode (mesh), the electric field induces ionization in the surrounding air molecules and polarizes the aerosol. This ionization process involves the removal of electrons from the air molecules, leading to the creation of positive ions and free electrons. The negatively charged electrode exerts an attractive force on the positive ions within its proximity. Consequently, these positive ions are drawn towards the electrode due to coulombic attraction. Positive ions can either reach the negative electrode or come into contact with the polarized aerosol. If a polarized aerosol encounters a positive ion or a free electron, the aerosol droplet acquires a net negative or positive charge, respectively. As a result, it can adhere to the electrode. This process can be regarded as a trapping mechanism for capturing contaminated aerosols (Fig. 4) [18-20].

The electric field near the positive point electrode is highly concentrated and intense. As a result of this strong electric field positively charged aerosol droplets are not allow to pass the positive electrode. This arrangement of electric field acts as a barrier for charged aerosol droplets.

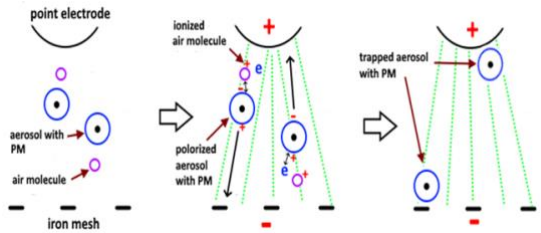

Fig. 4. Charging and trapping mechanism of aerosols with electric field

C. *Mechanism of Purification*

First, exhausted gas from vehicle is entered to the cyclone filter so gas is in swirling motion toward the bottom of the cyclone filter while making contact with detergent aerosol which is coming from aerosol generators. Larger and heavier particles in gas are migrated towards the walls of the cyclone filter because of the centrifugal force and they are washed down with detergent subsequently. Detergent aerosol acts as a surfactant, enhancing the interaction between the aerosol and the particles, facilitating their dissolution and subsequent capture by filtrations. This innovative approach aims to improve the overall particulate matter removal efficiency, especially for hydrophobic and stubborn particles that may be resistant to conventional filtration methods.

The remaining aerosol mixture, consisting of PM particles with detergent aerosol droplets, is directed into the electrostatic barrier. Here, these particles have two possible outcomes: they can either adhere to the electrodes or be pushed back towards the cyclone filter. This behavior is a result of the electric field's influence, as previously discussed. The primary purpose of this stage is to ensure that aerosol droplets do not escape from the purifier.

D. *Detection of PM*

Monitoring and detecting PM concentrations in the exhausted gas is crucial. The PM monitoring unit (Figure 05) was made with the SDS011 sensor and few other electronic components (arduno-nano, oled display, etc.). It can be used for measuring PM levels in real-time. The SDS011 sensor is an optical air quality sensor specifically designed to measure $PM_{2.5}$ and PM_{10} concentrations. It utilizes a laser-based scattering principle to detect and quantify the concentration of particles suspended in the air. The sensor consists of a laser diode that emits light and a photo-detector measures the scattered light intensity. By analyzing the amount of scattered light, the sensor can estimate the concentration of $PM_{2.5}$ and PM_{10} particles in the surrounding environment [21, 22].

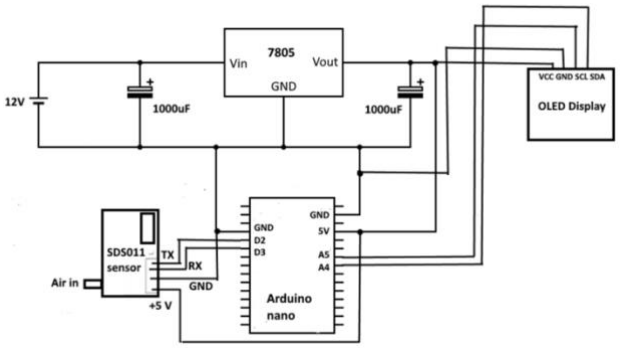

Fig. 5. Circuit diagram of PM monitoring unit

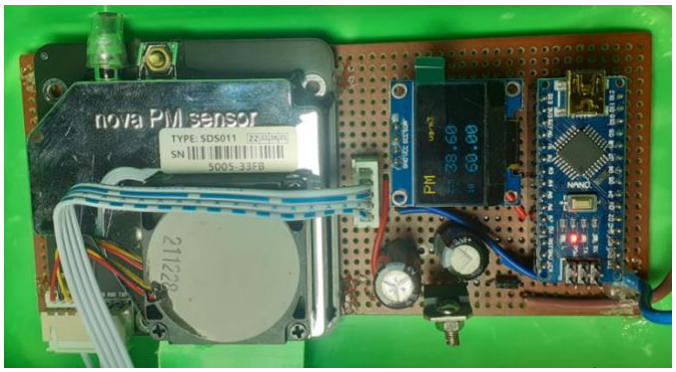

Fig. 6. PM monitoring unit with SDS011 sensor, OLED display with arduino nano

III. Experimented Results

1. *Testing Purifier Unit with Diesel Vehicle*

The experiment involved the use of a Nissan Vanette diesel van as test vehicle. Initially, the concentration of particulate matter (PM) in the exhausted gas was recorded with PM detector without attaching an emission purifier unit. Throughout the experiment, the van was maintained in neutral mode without acceleration. Subsequently, the emission purifier unit was affixed to the van's tailpipe. To identify the dispersion of PM in detergent liquid, the cellulose filter was temporarily removed, and detergent liquid was collected in a transparent container for duration of 10 minutes. The transformation of the detergent liquid from green to black with time was observed through visual inspections (Figure 06).

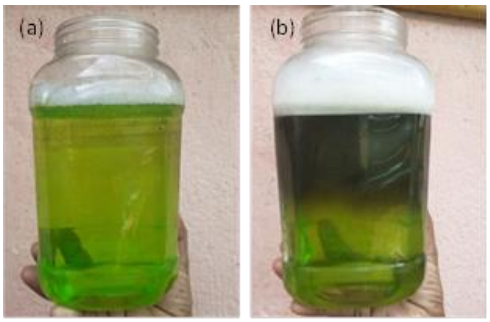

Fig. 7. Detergent liquid (a) initial and (b) after circulation through the system for 10 min

Then the collected samples of detergent liquid were characterized with UV visible spectroscopy

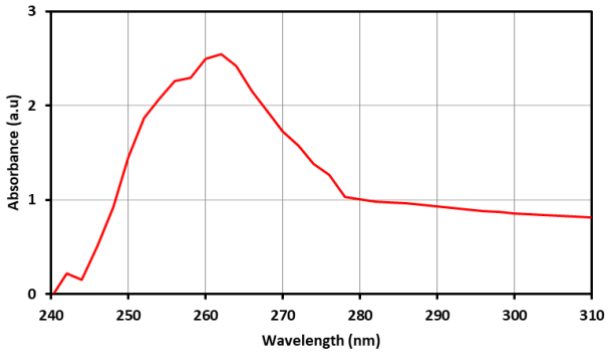

Fig. 8. UV-visible spectrum of detergent liquid with PM

The emergence of a peak within the UV-visible spectrum serves as a confirming indicator of the presence of a extrinsic substance which was coming from exhausted gas of vehicle compared to the pure detergent liquid. To further validate PM dispersion in detergent, three liquid samples were collected at varying circulation times. As the circulation time increased, it was evident that PM dispersion in the liquid had indeed grown, as confirmed by the heightened peak observed in the UV-visible spectrum (Fig. 8).

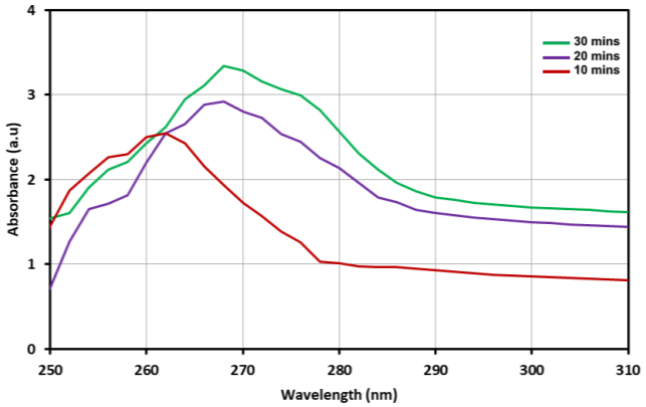

Fig. 9. UV-visible spectrum of collected detergent liquid after different circulation time of liquid

Prior to assessing the device's effectiveness, cellulose filter was installed back into the system. The exhaust gas from the vehicle was then directed into a purifier maintaining a constant flow rate during this process. As the gas exited the purifier, it was recorded the PM concentration along with the corresponding detergent concentrations. Subsequently, the PM reduction percentages and detergent percentages were calculated based on this data. Finally, it was graphically represented for analysis. This process allowed us to evaluate the performance of the device and its efficiency in reducing particulate matter emissions from the vehicle.

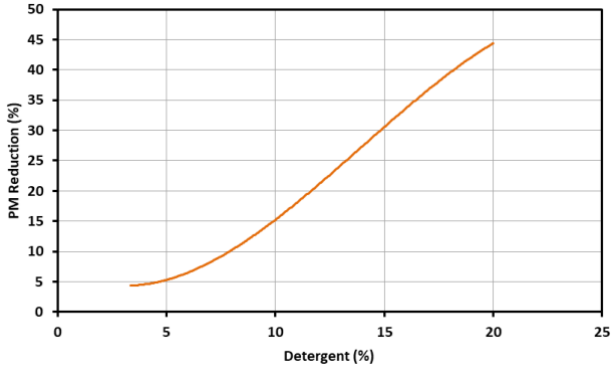

Fig. 10. The reduction percentage of PM with respect to the detergent liquid percentage

The graph indicates that as the detergent percentage increases, the reduction percentage of PM also rises. However, this increase in detergent content is accompanied by an elevation in liquid viscosity. Consequently, the escalating viscosity poses challenges to the filtration process of the contaminated liquid, primarily due to the thicker consistency of the liquid. In order to maintain continuous filtrations process, detergent percentage was kept at 20% and hence the maximum PM reduction percentage was 44% under the above conditions.

IV. Conclusion

The removal of particulate matter (PM) from vehicle exhaust gases, particularly using the novel detergent aerosol method, was successfully demonstrated through this innovative approach. It was validated through visual inspection and further confirmed via UV-visible spectroscopy. In the entire purification process of this device, detergent aerosols serve as the primary cleaning agent, while the electrostatic barrier technique is employed as a secondary step to prevent the bypassing of any remaining aerosols. When examining the gas flow path of the purifier, it's important to note that there are no barriers, ensuring that there is no increase in engine pressure of the vehicle. This presents a significant advantage compared to commercial and industrial smoke purifiers. Being the initial prototype, this device is primarily befitted for diesel vehicles, especially those with substantial emissions like public buses. However, there is potential for further advancement to create a smaller, more compact device suitable for all types of automobiles. Automation can be incorporated to dynamically adjust aerosol generation speed in response to vehicle acceleration, achieved through enhancements in the filtration and detergent liquid recycling processes. Moreover, this study will provide valuable insights for automotive manufacturers and researchers, fostering informed decision-making in the pursuit of more environmentally friendly transportation system by bridging the gap between theory and practice, also this research aim to contribute to a cleaner and healthier environment for current and future generations.

V. Acknowledgements

This work was supported by the RRSG project at SLTC. (Grant No: RRSG.22.0712.1)

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2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

AoI Based UAV Wireless Communications Networks

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***Abstract*—This paper presents the potential application of Age-of-Information (AoI) in Unmanned Aerial Vehicles (UAVs) assisted wireless networks. Specifically, the study utilizes the Average Age of Information (AAoI) and Peak Average Age of Information (PAAoI) metrics to measure information freshness in such networks. This study analyzes the impact of several factors on AAoI and PAAoI, including Active Probability, Block Length, Number of Nodes, Power, and Update Size. The findings underscore the significance of AAoI and PAAoI in the design of future mission-critical wireless networks.**

***Index Terms*—Age of Information, Peak Average Age of Information, Wireless Networks and Block Length.**

I. Introduction

Unmanned Aerial Vehicles (UAVs), commonly called drones, have brought about a significant revolution across diverse industries by offering highly efficient and cost-effective solutions [1]–[5]. Their potential in various applications, including aerial photography, disaster management, environmental monitoring, and delivery services, has garnered widespread recognition. Among recent advancements in this field, integrating UAVs into wireless networks as mobile base stations (BSs) stands out as a transformative development that can revolutionize connectivity and ensure real-time data freshness in the ever-evolving Internet of Things (IoT) landscape [6]–[11].

Despite the promising prospects of UAV-aided wireless communication, several challenges exist. One of the main challenges in UAV communication is the preservation of information freshness at the destination, particularly considering that most UAV-assisted communication networks serve mission-critical purposes. On the other hand, the Age of Information (AoI) is a critical metric in time-sensitive applications, where the timeliness of the information can be as important as the information itself [12]–[14]. Moreover, AoI has gained significant attention due to its ability to accurately measure the freshness of information at monitoring points, surpassing the limitations of traditional end-to-end latency [15], [16]. In recent years, there has been significant research interest in estimating the AoI within UAV-aided communication networks. For example, in a recent study [15], [17], an AoI-based wireless communication system was introduced, employing UAVs as relays to investigate the influence of UAV deployment on the freshness of the information. These studies contribute to understanding AoI dynamics in UAV-assisted wireless networks. By exploring factors such as computing resources, UAV deployment strategies, and relay configurations, researchers aim to enhance overall performance and information freshness in future wireless communication systems.

In the realm of disaster-resilient wireless networks, the integration of Simultaneous Wireless Information and Power Transfer (SWIPT) with Intelligent UAV deployment, complemented by a focus on the AoI, represents a revolutionary advancement [4], [10]. This synergy is pivotal in creating a robust communication infrastructure that is not only sustainable but also efficient in maintaining the freshness of information, a critical factor in disaster management. Intelligent UAV deployment, optimized through real-time analytics and adaptive strategies, ensures effective coverage in disrupted or inaccessible areas. Incorporating SWIPT allows these UAVs to harvest energy while simultaneously processing and disseminating vital information. This capability is crucial for sustaining operations in prolonged emergency scenarios [18]. Moreover, by prioritizing AoI, this integrated approach guarantees that the information relayed is not only timely but also relevant, which is essential for coordinating swift and effective disaster response strategies [19], [20].

This study focuses on the exploration of AoI metrics, specifically the Average Age of Information (AAoI) and Peak Age of Information (PAAoI), within the context of a wireless network that employed UAVs. The analysis conducted provides profound insights into the performance characteristics of UAV-assisted wireless networks, thereby offering crucial guidance for their design and optimization.

II. Age Of Information metrics in Uav-Assisted Wireless Networks

Consider a simplified communication system consisting of a source-destination pair. In this system, the source transmits timely updates to a network, delivering these updates to the destination. When the generation time of the most recent

This work was supported in part by the COFAC - Cooperativa de Formação e Animação Cultural, C.R.L.(University of Lusófona), via the project AOEE-WiPS (COFAC/ILIND/COPELABS/2/2022), by the national funds through FCT - Fundação para a Ciência e a Tecnologia - as part the project AIEE-UAV(no. 2022.03897.PTDC) and COPELABS (no. UIDB / 04111/2020).

update received by the destination at timestamp t denotes $g(t)$. The AoI can be then described as $\Delta(t) = t - g(t)$.

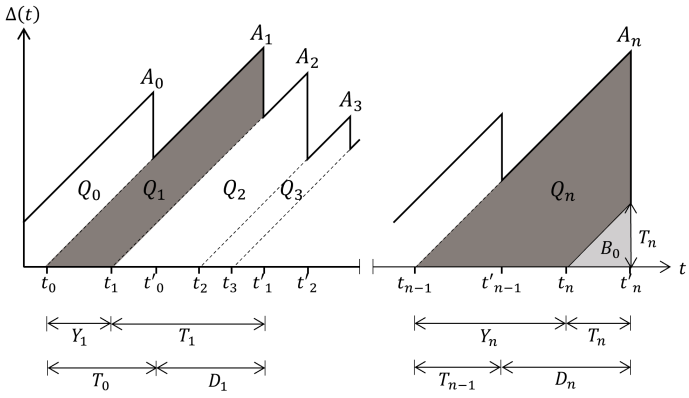

Fig. 1. Example of age evolution

As shown in Fig. 1 $t_0, t_1, \ldots$ are arrival times of updates from a source, and $t'_0, t'_1, \ldots$ is the time they are received on the monitor. Y_n is the inter-arrival time, D_n is the inter-departure times between two updates and T_n is the system time of the n_{th} update. A_n is the corresponding age peak. The aging process $\Delta(t)$ peaks the instant before the service completion at time t'. Suppose that our interval of observation is $(0, \tau)$ and $N(\tau) = \max\{n \,|\, t_n \leq \tau\}$ is the number of updates by time τ. Then, time average AoI can be calculated as

$$\Delta_\tau = \frac{1}{\tau} \int_0^\tau \Delta(t)\, dt, \tag{1}$$

where $\Delta(t)$ represents the age of a status update at time t. Furthermore, The integral in (1) decomposes the polygon area $\bar{Q}_0$, the sum of the trapezoidal areas, $Q_j \longrightarrow 1 \leq j \leq N(\tau)$ and B_0 triangular area of width T_n. Then, (1) can be reformulated as follows $\Delta_\tau = \frac{1}{\tau}\left[\bar{Q}_0 + B_o + \sum_{j=1}^{N(\tau)} Q_j\right]$.

Alternatively, (II) can be written as $\Delta_\tau = \frac{\bar{Q}_0 + B_o}{\tau} + \frac{N(\tau)}{\tau} + \frac{1}{N(\tau)} \sum_{j=1}^{N(\tau)} Q_j$. Then, the trapezoidal area can be calculated as:

$$Q_n = \sum_{j=1}^{N} Q_j = \frac{1}{2}\left[(t'_n - t_n) + (t_n - t_{n-1})\right]^2 - \frac{1}{2}(t'_n - t_n)^2 \tag{2}$$

Substituting $t'_n - t_n = T_n$ and $t_n - t_{n-1} = Y_n$ to (2), Q_n can be derived as follows :

$$Q_n = T_n Y_n + \frac{Y_n^2}{2}. \tag{3}$$

The time average Δ_τ tends to the ensemble average age as τ tends to infinity as $\Delta = \lim_{\tau\to\infty} \Delta_\tau$. Hence, AAoI can be derived as follows:

$$\text{AAoI} = \Delta = \lim_{\tau\to\infty} \frac{1}{E[Y_n]} E[Q_n] \tag{4}$$

Then, (4) can be reformulated using (3) as follows [1]:

$$\text{AAoI} = \Delta = \frac{E[Q_n]}{E[Y_n]} = \frac{E[T_n Y_n] + \frac{E[Y^2]}{2}}{E[Y_n]} \tag{5}$$

Moreover, the peak age of information at the t'_n can be calculated as follows:

$$A_n = T_{n-1} + D_n \quad \text{or} \quad A_n = Y_n + T_n. \tag{6}$$

Suppose that our interval of observation is $(0, \tau)$ and $N(\tau) = \max\{n \,|\, t_n \leq \tau\}$ is the number of updates by time τ. The time average peak age of a status update system can be formulated as follows:

$$A_\tau = \lim_{\tau\to\infty} \frac{1}{N(\tau)} \sum_{n=1}^{N(\tau)} A_n \tag{7}$$

Furthermore, (7) can be reformulated using (6) as $A_\tau = E[A_n] = E[T_{n-1}] + E[D_n] = E[T_n + Y_n]$. Then, the difference between AAoI and PAAoI can be calculated as

$$\Delta - A_\tau = \lambda \left(E[T_n Y_n] + \frac{E[Y_n^2]}{2} - E[Y_n]E[T_n] - E[Y_n^2] \right), \tag{8}$$

where $\lambda = \frac{1}{E[Y_n]}$.

III. SIMULATION RESULTS

In this section, numerical results are presented to validate the theoretical derivations. Fig. 2 illustrates the impact of source active probability on the difference between AAoI and PAAoI. The results indicate that as Active Probability increases, the difference between PAAoI and AAoI increases for both theoretical and simulated values.

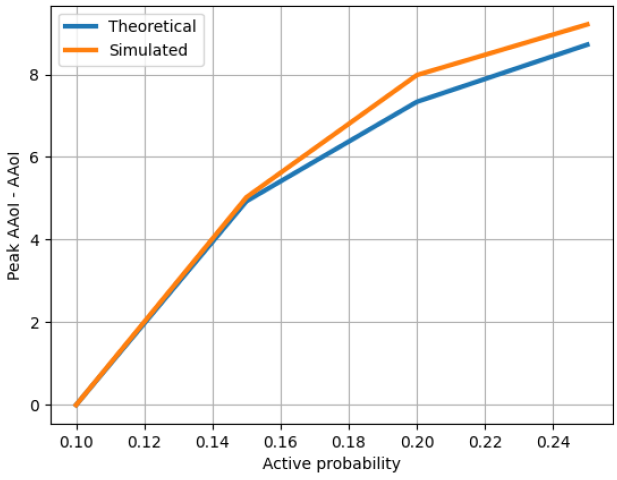

Fig. 2. Difference between PAAoI and AAoI vs Active probability

[1]When $\tau \to \infty$, $\frac{\bar{Q}_0 + B_0}{\tau} \to 0$, $\frac{N(\tau)}{\tau} \to \frac{1}{E[Y_n]}$ and $\frac{1}{N(\tau)} \sum_{j=1}^{N(\tau)} Q_j \to E[Q_n]$

IV. Conclusion

In conclusion, this paper presented AAoI and PAoI in a wireless network assisted by UAVs. By studding the factors such as Active Probability, Block Length, Number of Nodes, Power, and Update Size, this study aimed at improving the significance of AAoI and Peak PAAoI in the future wireless network design. The findings support the adoption of these metrics to improve information freshness and network performance. In the future, a comparative analysis of the impact of Active Probability, Block Length, Number of Nodes, Power, and Update Size on AAoI and PAAoI will be conducted. In addition, we will present a new theoretical framework to validate these findings.

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2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

Computer Vision and Deep Learning Based Assistance System for The Visually Impaired

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***Abstract*—The creation of algorithms and methods for computer vision enables machines to comprehend visual input at a deep level, including photos and videos. By giving computers the ability to decipher and analyse visual data, identify things, and comprehend their surroundings, it seeks to mimic human vision. This project aims to develop an assistance system for the visually impaired. The proposed system will use a camera mounted on a wearable device to capture the surrounding environment. This system will function according to the computer vision techniques to detect and recognize objects, pathways, and pedestrian crossing and convert to text, in real-time. First, we have collected datasets of objects, pathways, and pedestrian crossing then we will annotate our data set with Roboflow and train with YOLO V8. By giving voice navigation it will be able to assist the user. If the objects detect then we will convert those objects into text format. After that, we will convert the text into the voice. The system will employ a deep learning (DL) model to classify the detected objects and a separate pre-trained DL model to provide audio feedback to the user through earphones. The obstacle detection module of this system will also use depth sensing techniques to detect and alert the user about potential obstacles in their path. The user will have the ability to interact with the system using voice commands, which are processed using natural language processing algorithms. The system's accuracy and effectiveness will be evaluated using user studies and benchmark datasets.**

Keywords—Computer vision, object detection, image segmentation, text recognition, audio feedback, and natural language processing

I. INTRODUCTION

As of 2017, the Sri Lanka Federation of the Visually Handicapped reported around 70,000 registered blind persons in Sri Lanka. To aid them, we have planned to implement a system. That is a computer vision and Deep learning-based assistant system for the visually impaired.

Computer vision techniques combined with deep learning can play a significant role in developing an assistant system for visually impaired individuals. Such a system can help them perceive and understand their surroundings, navigate safely, and access visual information. Object detection algorithms can be employed to detect and locate various objects in the environment, including obstacles, pedestrians, vehicles, and important landmarks. This system can offer real-time audio or haptic feedback to guide visually impaired individuals during navigation.

In this modern world, every activity is interrelated with technology. These technologies assist us in our day-to-day activities. Therefore, we have planned to implement an assistance system for the visually impaired with the help of technology. Visually impaired people are facing many difficulties in theirlives. They have to depend on others when they go out alone.Our aim is to make them function without others' assistance.Our system is to be designed in such a way that the visually impaired can be able to identify all the things that are on the road. There are plenty of assistance systems for the visually impaired in the world market, but our system we try to make that system more user-friendly. While the visually impaired person walking along the road, pathway, pedestrian crossing, and objects will be detected and give voice navigation about them. In addition to that, this system also helps to prevent accidents by giving voice alerts.

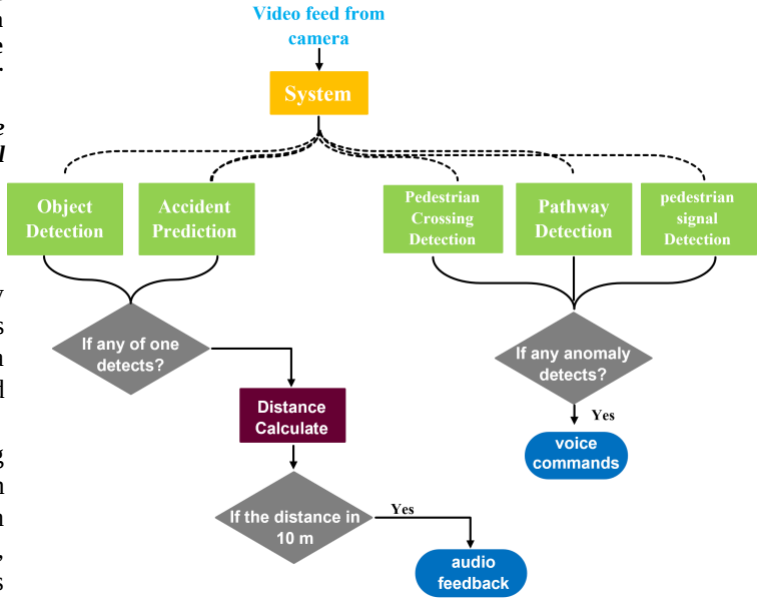

Fig. 1. Overview of project

II. System Model

This block diagram clearly shows how our models will train. The training datasets will go through image pre-processing and feature extraction first. after finishing those, we need to train the model using the YOLO V8 algorithm. After the training process, we will get a trained model. Using the trained model, we need to recognize our system. so, for the recognition testing datasets will go through image pre-processing and feature extraction first. later the trained model will analyse the output from testing datasets and show us in the display. Now people understand what is happening in front of them.

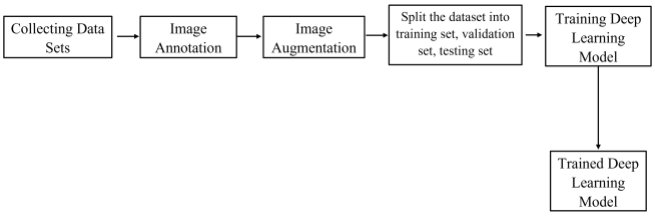

Fig. 2. Block diagram of models

III. Related Work on Literature

To aid visually impaired people in social interactions, an electronic device with obstacle detection and face recognition has been developed. The proposed device was in the shape of smart eyewear that has an ultrasonic sensor and Pi camera with a Raspberry Pi installed. The Raspberry Pi, which is coupled to the ultrasonic sensors, receives data signals from the sensors for additional data processing and can detect impediments up to 1000 cm away from the user. A pi camera is used to recognize the person in front of the visually challenged according to the database list. This gadget makes it simple to recognize people. It is an inexpensive, power-efficient device [1].

Produced low-cost, dependable, transportable, user-friendly, sturdy Smart Glasses for those with visual impairments for easy navigation. The device is affordable and wearable like glass. The device features a built-in sensor that sends out ultrasonic waves in the direction the user is moving and has a maximum scanning range of 5–6 meters. The system's earliest iterations relied on simple image processing and computer vision techniques, and additional improvements were developed to identify a secure path for user movement. When an obstacle is there, the sensor picks it up and sends the information to the gadget, which then automatically produces a speech that the user may hear through an earpiece [2].

Presented a system for blind persons to use to detect and identify outdoor barriers. Their system was given a new obstacle detection dataset called OD that contains 15 typical objects and was used as a new baseline for outdoor obstacle detection. Three object identification techniques, including YOLO, SSD, and Faster RCNN, were utilized in their research to determine the optimum model for object detection. The evaluation results showed that the YOLO algorithm outperformed the other two algorithms [3].

Suggested a Blind Sight-Object Detection system that is based on cutting-edge object detection technologies and computer vision. The technology seeks to automate things that the human visual system can do. The features of the image are recognized and assigned to the correct class using image classification algorithms. The 123,287 hand-labeled images that make up the COCO dataset, which was employed in this experiment, are divided into 80 categories. The spatial relation- ships between things and their locations in the environment are described using this vast collection of data. This system uses the Object Detection Framework You Only Look Once to find objects. To distinguish the monetary denominations, a module for recognizing Indian currency was also created [4].

Presented a navigation aid for visually impaired persons to help them with autonomous direction. A camera, single-board DSP processor, wet floor sensor, battery, and a variety of sensors and processing components make up the entire system for those with vision impairments. To help the user become accustomed to the environment, the machine learning model was employed for object recognition. The proposed gadget was utilized to identify obstructions, stairs, potholes, speed bumps, wet flooring, and tight spaces in order to provide the best navigational direction. The output was delivered in the form of the vibration, to inform the user about the impediment [5].

IV. Computer Vision Approach

Computer vision consists of techniques for obtaining, processing, analyzing, and understanding images. In general, it can produce high-dimensional information from the real world to numerical or symbolic information. In a scientific area, computer vision is involved with the theory behind artificial systems and it can extract information from images. The data from the image can be taken in many ways, such as video sequences, from multiple cameras, or multi-dimensional data from a medical scanner. As a technological improvement computer vision systems seek to apply computer vision theories and models. Sub-domains of computer vision include video tracking, object recognition, event detection, learning, indexing, motion estimation, and more [6].

A. Dataset Collection

Machine learning is divided into many subcategories. Supervised learning is one of the subcategories of machine learning and artificial intelligence. For supervised learning, we have to teach or train the machine using data that are well-labeled. Supervised learning is highly accurate rather to unsupervised learning. We need datasets for supervised learning. So, we collected datasets for objects, pathways, and pedestrians crossing while walking into the path.

B. Training

For the training, we used the YOLO v8 algorithm. We cloned the YOLO GitHub repository into google Colab and started training the model. For the training, we used 50 epochs. Epochs mean the number of times the learning algorithm will go through the training datasets. For the training, it took a lot

of time. It took 4 hours. Like that, each of the training takes a lot.

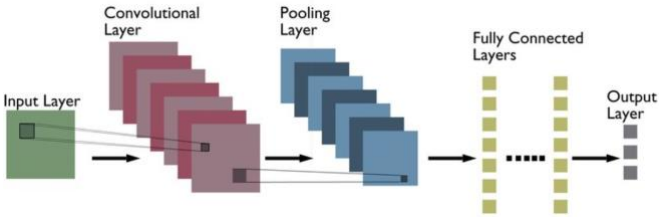

Fig. 3. Architecture of CNN

The algorithm we are planning to use here is Convolutional Neural Network (CNN) [7]. The convolutional neural network may be a profound learning neural organization outlined for preparing organized arrays of information such as pictures. Convolutional neural networks are broadly utilized in computer vision and have gotten to be the state of the art for numerous visual applications such as image classification, and have moreover found success in normal language processing for text classification. They are specifically designed to process pixel data and are used in image recognition and processing. So, we think our system will be most effective if we use Convolutional Neural Network (CNN).

Figure 3 shows how CNN algorithms work on this project. The first convolution layer simplified this complex image. The filtering process happens in this layer. The next layer is the pooling layer. This layer makes the process much faster and it creates a pooled feature map. After that, the upcoming layers extract small features, So the output will be highly accurate.

V. Results

We have planned to show the results of our trained models on object detection, pathway detection, and pedestrian crossing detection. The objective of our research is to develop effective and accurate algorithms for detecting objects, pathways, and pedestrian crossings in real-world scenarios. We evaluated our models on a different dataset comprising different urban and suburban environments.

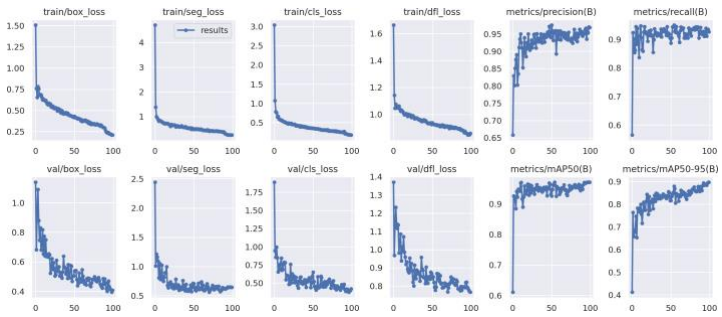

Fig. 4. Training, validation losses graph

In the above figure, 4 clearly shows the training losses and validation losses. Our object detection system was prepared to employ a state-of-the-art deep learning architecture, particularly leveraging the YOLO (You Only Look Once) algorithm. The model was initialized with a pre-trained YOLO modelon an expansive annotated dataset containing a wide range of objects, including vehicles, people, posts, and traffic lights, as well as pathways, pedestrian crossings, and pedestrian signals. This pre-training ensures that the model benefits from the knowledge gained on a large-scale dataset, enhancing its ability to generalize to diverse object categories. During the evaluation stage, we measured the execution of our object detection framework using well-established metrics such as accuracy, precision, recall, and the F1 score.

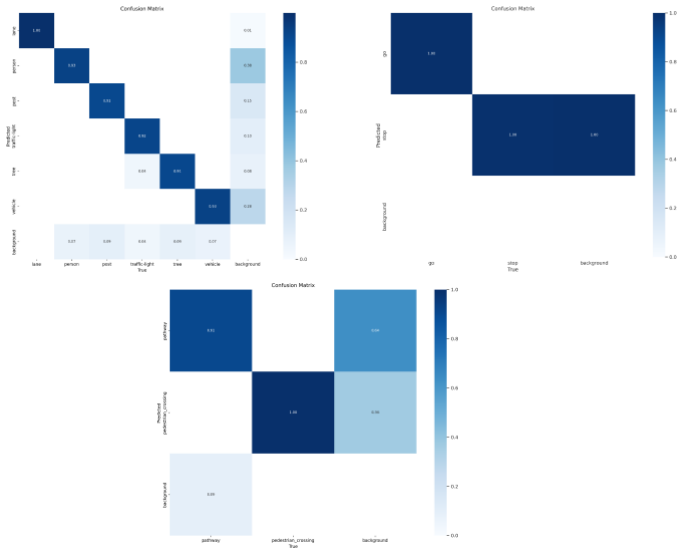

Fig. 5. Validation graphs

The confusion matrix depicted in Figure 5 provides a comprehensive evaluation of the performance of our trained model. The matrix illustrates the distribution of true positive (TP), truenegative (TN), false positive (FP), and false negative (FN) pre-dictions across different classes. This visualization is crucial for assessing the model's ability to accurately classify objects within the given dataset. High values along the diagonal indicate successful predictions, while off-diagonal elements highlight instances of misclassification. The precision, recall, and F1-score metrics derived from the confusion matrix furtherquantify the model's efficacy in terms of both precision and recall, offering insights into its overall classification performance. The detailed analysis presented in this section servesas a critical reference for understanding the strengths and potential areas of improvement in our model's object detectioncapabilities.

VI. Future Works

As part of our future work, we are planning to enhance the functionality of our system by connecting the mobile phones of visually impaired individuals via Bluetooth. This connectivity will enable our system to provide valuable assistance, including location tracking, checking current weather conditions,

and facilitating communication with housemates. To further enhance the object detection capabilities of our system, we are exploring the integration of sensor technologies. Specifically, we plan to incorporate ultrasonic sensors to augment object detection. These sensors offer real-time distance measurements, allowing for a more robust and accurate detection of obstacles and objects in the user's vicinity. By leveraging sensor datain conjunction with our deep learning-based object detection framework, we aim to provide a comprehensive and reliable assistance system for individuals with visual impairments.

VII. Conclusion

The proposed assistance system for the visually impaired can be a powerful tool for accomplishing their daily tasks, providing them with greater independence, and improving their quality of life. The system can recognize objects, read printed materials, and provide navigation assistance by leveraging the latest advancements in computer vision and deep learning. The development of such a system requires a multi-disciplinary approach, bringing together experts in computer vision, deep learning, natural language processing, and user experience design. The system should also be designed with inclusively in mind, ensuring that it meets the needs of a diverse range of visually impaired individuals. Overall, the development of this system for visually impaired individuals is an exciting area of research and has the potential to significantly impact millions of people worldwide.

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2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

Interpretation of Music Signals Using Time-Frequency Analysis

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***Abstract*—Time-frequency analysis serves as a pivotal tool in unraveling the intricate dynamics of signals evolving over time. Through the meticulous dissection of signals into their frequency components at specific time intervals, this method provides a nuanced understanding of transient events. This capability empowers researchers and practitioners to discern temporal patterns and unveil hidden structures within complex data, enhancing their ability to extract valuable insights from dynamic signal variations. In the present study, the methods of Time- frequency analysis is used for a qualitative analysis of music signals. The Short Time Fourier Transformation (STFT) and Continuous Wavelet Transformation (CWT) were investigated to discover music signal interpretations. The results of frequency approaches with time were implemented using Python Programming Language as Spectrograms and Scalograms.**

Keywords—Time-frequency analysis, STFT, spectrogram, CWT, scalogram

I. Introduction

Signal processing has been completely transformed by the use of time-frequency approaches, particularly in the analysis of musical signals. They provide a special method for analyzing and interpreting signals' complex and dynamic properties in both the time and frequency domains. The Short-Time Fourier Transform (STFT) was first introduced by Gabor in the early 20th century, which is when time frequency analysis began to take shape. Lately, wavelet transforms, spectrograms, and more sophisticated methods like the Continuous Wavelet Transform (CWT) and the Discrete Wavelet Transform (DWT) contributed to the field's substantial developments. Time-frequency techniques are used in a variety of industries, including wireless technology, seismic data analysis, voice processing, biological signal processing, and image processing. In terms of thorough representation, transcription and score following, feature extraction for pitch, rhythm, and harmony, and music classification, time-frequency approaches have benefits in the study of music signals. In addition to giving detailed information on musical content, they aid in detecting musical variations, distinguishing between instruments, transcribing music, extracting features for information retrieval and automatic music recommendation systems, and etc. The present study uses time-frequency methods to uncover such characteristics of music transmissions.

II. Time Frequency Analysis

Time-Frequency Analysis is the study of the frequency variations of signals with respect to time. Various types of time-frequency analysis techniques can be used in real-world situations in order to discover the information that lies within non-stationary signals. For the analytical modification of various sorts of signal processing applications, the Fourier Transformation was developed further. As an approach for time-frequency analysis, the Short-Time Fourier Transformation (STFT) was initially established. The Continuous Wavelet Transform (CWT) was a technique that was later developed and is capable of being used in a variety of signal processing applications. [4] Both techniques are beneficial for musical signal processing since finding information results in inventive musical solutions.

A. Short-Time Fourier Transformation

The Short-Time Fourier Transform (STFT), introduced by D. Gabor in 1971, is a signal processing method that examines a signal's time-frequency properties. It is also known as Gabor Transformation which uses a window function to split a larger signal into shorter segments, calculates the Fourier Transform for each windowed segment, and outputs a spectrogram, which is a representation of the signal's time and frequency. The STFT is frequently used in vibration analysis, voice analysis, and audio signal processing.

B. Continuous Wavelet Transformation

A time-frequency analysis method known as the Continuous Wavelet Transform (CWT) analyzes the localized frequency content of a signal over time. It is also known as Multi-resolution Analysis and involves visualizing a signal as a scalogram and is based on wavelets, localized functions in both time and frequency. CWT is the convolution of the signal with a scaled and translated version of the wavelets and finds applications in scientific research, image analysis, and signal processing.

III. Gabor Transformation (STFT)

A. Fourier Transformation (FT)

Fourier Transformation is a mathematical technique introduced by J.B. Joseph Fourier in the 19th century. It decomposes complex signals into sine and cosine waves, revealing the signal's frequency components. The transformation is represented mathematically converting signal functions from time domain to frequency domain which are absolutely integrable and piecewise smooth.

i.e. taking the signal function over time domain to be *f(t)*, the function is well defined and integral of the function is not divergent and clearly exists which implies the integral is convergent over time domain. [2] One continuous function is

transformed at a time by the operation, which was the primary driver behind continued development of the transformation.

B. Discrete Fourier Transformation (DFT)

Discrete Fourier Transformation is a modification of FT which can be used to transform set of stationary functions at a time to its frequency components. The method was introduced by Carl Friedrich Gauss (1777-1855) which involved with computations with matrices to obtain the Fourier Transform of a signal. In DFT, if the number of data functions to be considered is *n*, then n^2 number of operations is conducted in order to output *n* number of frequency components as a sum of FTs.

Initially, the Discrete Fourier Transform (DFT) held prominence in signal processing studies. However, as the demand arose for the analysis of extensive datasets, exemplified by instances involving a considerable number of data points (such as 10^{10}), there emerged a necessity for a more sophisticated approach.

C. Fast Fourier Transformation (FFT)

FFT, introduced by J. Cooley and J. Tuckey around 1965 is a convenient computational algorithm of DFT which involves *(n log n) number* of operations for *n* number of data points [1]. The transformation classifies the number of data points continuously into odd and even functions and reduces calculations further and output computational finite sum of Fourier Transformations.

D. Windowing and STFT

The Short-Time Fourier Transformation is used for non-stationary signals with the aid of a suitable windowing function. [1] Applying a windowing function that is compactly supported and overlapped to the signal considers small chunks of the original signal for the transformation. Different types of windowing functions which changes their applications used according to the characteristics are:

- Hann Window (J.V. Hann, 1928)
- Hamming Window (R.W. Hamming, 20th cent.)
- Gaussian Window (C.F. Gauss, 19th cent.)
- Shannon Window (C. Shannon, 19th cent.)

The convolution theorem to the original signal and window function results a sequence of functions of FFTs. The convolution theorem in time domain results a product of two frequency components; signal component and shifted window function.

i.e. a finite sequence of $\mathcal{F}(f(t_k)).\mathcal{F}\big(w(t_k-\tau_k)\big)$

E. Spectrogram Analysis

The sequential implementation obtained in STFT results the time- frequency variations of the signal in one frame which is known as, **Spectrogram.** [6] It is a representation of the intensity plot of the STFT magnitude showing at which time durations the respective frequencies occurred at in the signal. The variations of frequencies (Y- axis) with respect to the time (X- axis) can be plotted using a computer programming software. In this study, Python is used to generate spectrograms with corresponding arguments.

IV. Interpreting a Music Signal Using STFT

A. Music Signal

As the first attempt of interpretation, analysis of a portion of a 14-second sound signal is used to identify major characteristics of a spectrogram, which is a raw piano input. The sound signal was extracted from the chorus of the song, **"Mary Had a Little Lamb".**

B. Solution by Python

The Python solution contained libraries for the plot of spectrogram and arguments of sending the audio file as an input, arguments of windowing and FFT process and arguments of plotting were feed into the code. The different values for nperseg, noverlap, nFFT arguments output different spectrograms with visible changes. In Python, the default window in use is Hann Window which automatically aid in implementing the spectrogram. Use of any window that is not Hann has to be defined in the programme.

The nperseg value corresponds to the number of segments per windowing at one time or window width and noverlap is giving the number of segments that are going to be overlapped with windowing before and after the current consideration. nFFT value corresponds to the number of data points that the audio signal is chunked into for applying FFT.

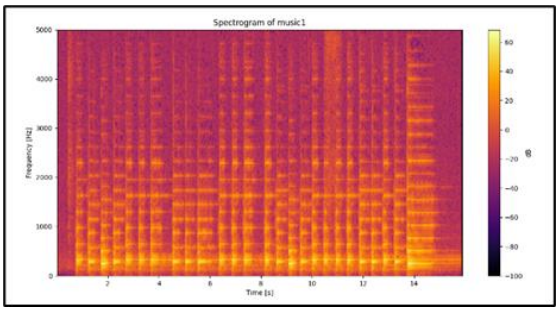


Fig. 1. Resulting Spectrogram with nperseg-2048, noverlap-1024, nfft-2048

C. Spectrogram Analysis–Varying Window width

The spectrogram observed for a large value for nperseg implements with better frequency resolution but lower time resolution which is known as **"Under-sampling"** of a signal. In contrast, **"Over- Sampling"** occurs when nperseg is lower results with higher time resolution but poor frequency resolution. (Fig. 2)

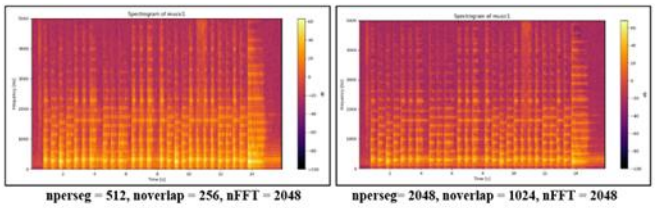


Fig. 2. Over- Sampling and Under- Sampling

D. Spectrogram Analysis – Varying Number of Data Points

The spectrogram obtained for higher values of nFFT implements spectrograms with finer frequency details of the signal but with poor time resolution. The lower nFFT values outputs a spectrogram with rapid time changes but with poor frequency resolution. (Fig. 3)

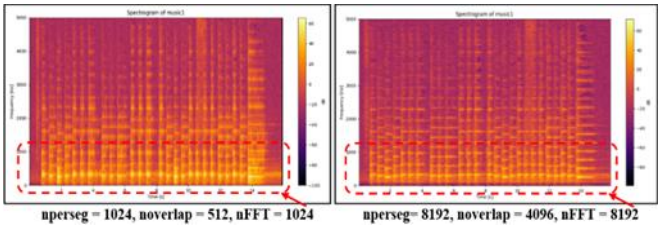
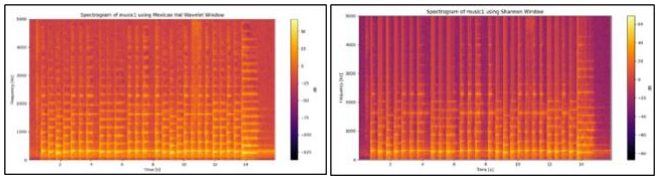


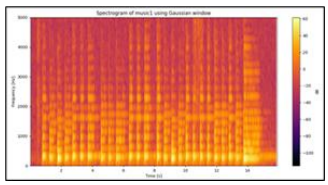
Fig. 3. Rapid Time changes and Finer Frequency Details with the change of nFFT

E. Spectrogram Analysis – Varying the type of window

The Mexican Hat Wavelet window, Shannon Window and Gaussian Window were defined and applied to the sound signal to investigate the features of resulting spectrograms. (Fig. 4)



(a) (b)



(c)

Fig. 4. Spectrograms implemented using (a) Mexican hat wavelet window, (b) Shannon window and, (c) Gaussian window

V. Continuous Wavelet Transformation

According to Weiner Heisenberg's (1901–1976) uncertainty principle [8], [12] encoding time and frequency data of a signal simultaneously is essentially challenging.

The Heisenberg Uncertainty Principle: A function f and its Plancherel transform $\mathcal{F}(f)$ cannot both have arbitrarily small support.

As a consequence, CWT is also has been widely used in signal processing as a time-frequency analysis technique [8]. The CWT is particularly useful for analyzing signals that have non-stationary or time-varying characteristics. The transformation is constructed using a particular function called the **Wavelet Function**, which yields a CWT matrix (Scalogram) that visualizes the change in the frequency content of the signal over time at various scales.

A. Wavelet Function and CWT

The CWT is proceeded for non-stationary signals but offering insights into both high and low frequency components with their temporal evolution. [5] The transformation is carried out using a wavelet function denoted as $\psi(t)$ (mother wavelet) which can be scaled and translated prior using it to the signal unlike the window functions in STFT which had a fixed width for an instance. This function is typically a short-lived oscillation, and it is used to analyze the signal at different scales and positions in time. A wavelet function is only can be used if it satisfies two main constraints: zero mean as the admissibility condition and finite energy as the necessary condition [12].

i.e. $\int_{-\infty}^{\infty} \psi(t)dt = 0$ and $0 < \int_{-\infty}^{\infty} |\psi(t)|^2\, dt < \infty$

There are various types of wavelet functions where the type of the wavelet affects the characteristics of the analysis. [11] Types of wavelet functions can be mentioned as follows:

- Haar Wavelet (A. Haar, 1909)
- Morlet Wavelet (J. Morlet, 1983)
- Gabor Wavelet (D. Gabor, 1946)
- Daubechies Wavelet (I. Daubechies, 1960)

CWT is calculated by applying the convolution theorem to the audio signal and the complex conjugate of the scaled and translated wavelet function:

$$\mathcal{W}_{\psi}(f)(a,b) = \frac{1}{\sqrt{a}} \int_{-\infty}^{\infty} f(t).\psi^*\left(\frac{t-b}{a}\right) dt$$

where a is the scaling parameter and b is the translation parameter. [9], [10].

B. Scalogram Analysis

The CWT formula's continuous integral is calculated numerically. The wavelet and the signal convolve at multiple scales and positions by varying the scale and position parameters. The magnitudes of the wavelet coefficients of the signal at various scales and time localizations is represented by the entries in the CWT matrix and visually represented in the **Scalogram** [1]. The variations of scales (Y-axis) with respect to the time (X-axis) can be plotted in here. In this study, Python is used to generate scalograms with corresponding arguments.

VI. Interpreting a Music Signal Using CWT

A. Music Signal and the Solution by Python

The music signal used is the chorus of **"Mary Had a Little Lamb"** which was used in spectrogram analysis in the study of STFT. (Fig. 5) In the case, the python solution contains specific libraries for CWT algorithms and arguments to use wavelets and output scalograms for audio signals. "Width scale" is the main argument that can be varied to analyze the audio signal with different scalograms.

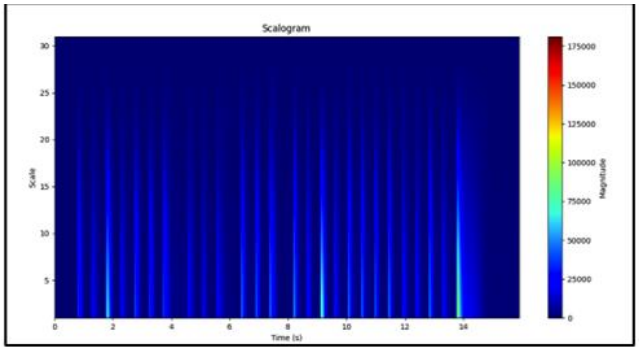


Fig. 5. Scalogram using morlet wavelet width= (1,31)

Width scale is an array of scales (or widths) that determines the range of scales for the wavelet and wavelet frequency represents the frequency of the oscillatory part of the corresponding wavelet which can be changed according to the frequency range of the signal. The wavelet that is being used has to be defined to the programme.

B. Scalogram Analysis–Varying Width Scale

The scalogram obtained for large scales is more sensitive to capture low frequencies of the signal averaging out high frequency components. The characteristic is useful to analyze slow changes and identify global patterns of the signal. The morlet wavelet is used for following observations. This property is advantageous in music signal processing to analyze musical expressions with related to the intensity of the sound and temporal changes (Fig. 6).

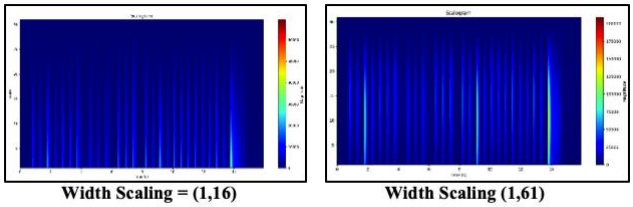


Fig. 6. Scalograms for different width scales of the same signal

VII. CONCLUSION

Implementing spectrograms with considerably higher values for nFFT with lower values for window width than nFFT value is allowed. Interpretation of higher nFFT values for sound signals with large number of instruments taking more time to implement but with fine frequency details. Bell-shaped curves, exemplified by Gaussian or Mexican Hat wavelets, prove highly effective in acute audio signal processing. In contrast, rectangular windows, such as the Shannon window, are not recommended as they fail to provide optimal data representation for this context. The use of bell-shaped wavelets ensures a more nuanced and accurate analysis of audio signals, capturing subtle variations and nuances that might be overlooked by less suitable windowing functions.

The interpretation of scalograms takes a significant leap forward with an advanced STFT model, where the flexibility of wavelets in scaling proves particularly advantageous for audio signals. In this refined approach, scaling is plotted in lieu of frequency over time, offering a more adaptive representation. The utility of wavelet transformation in audio signals lies in its capacity to capture not just frequencies but also the intensity or magnitudes at specific time instances. This characteristic becomes instrumental in analyzing the dynamic intricacies of musical expressions, such as crescendos and decrescendos, providing a nuanced understanding of sound evolution [3].

The integration of spectrogram and scalogram implementations opens up innovative possibilities, such as the creation of an interactive music instrument program capable of detecting and measuring user-initiated tempos. A promising avenue for future research involves the exploration of musical note recognition systems through spectrogram analysis, presenting opportunities to deepen our understanding of musical structures and enhance interactive music technology.

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2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

Community Capacity Development to Achieve Sustainable Development in Sri Lanka: Reviewing the concept of 'One Village One Product' in Japan

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***Abstract*—Community Capacity Development (CCD) leads to enhance communities' ability to recognize, plan and implement solutions to the challenges communities face. It includes many facets such as empowering community and institutions, by improving skills, imparting knowledge, providing resources and facilitating for networking. One Village One Product (OVOP) is a rural development approach originated in Japan. Through this process distinctive product or service peculiar to that particular village is identified. OVOP is implemented based on natural resources in that particular area, traditional skills people possess in that area and cultural heritage. Sri Lanka is struggling with achieving sustainable development goals as it faces many challenges due to economic crisis Sri Lankan experience. Sri Lankan economy is suffering from hyperinflation, devalued currency and huge sovereign debts. Not only country's economy but also economy of each individual and family is affected adversely. In this backdrop, this study has been conducted with the view to see the feasibility to implement OVOP techniques in some specific areas in Sri Lanka. Improving production and proper marketing of handicraft and face mask in Ambalangoda area is the main objectives of this study. In this research literature was reviewed to identify economic and social factors in this regard. Desk research has been carried out. In addition, participatory observation method has been adopted. Finally, recommendations have been provided.**

Keywords—Community capacity development, one village one product, sustainable development goals

I. INTRODUCTION

Community capacity development (CCD) refers to the process of improving a community's ability to identify, plan, and implement solutions to its own challenges. CCD provides to community members, organizations, and institutions with the skills, knowledge, resources, and it assists to build networks in order to address issues effectively.

A. Literture Reiview

a) The Key Dimensions of CCD

The key dimensions of CCD are empowerment, participation, asses-based approach, collaboration and networking, enhancing skills and training, local problem solving, ownership and sustainability, building resilience, advocacy and social change, evaluation and learning and cultural considerations.

Empowering individuals and communities to take charge of their own development is the main focus in this concept. Engaging actively in decision-making processes is also crucial in this regard. Asset-Based Approach means capacity development while identifying present strengths and resources within the community. This approach helps to develop on the unique assets, skills, and talents of their communities.

Collaboration between community members, organizations, governments, and other stakeholders are important too. Capacity development can be done through involves training, workshops, and opening educational opportunities to community members. This encompasses technical skills as well as skills related to leadership, management, and communication.

Through CCD communities are able to address their specific needs and challenges and that is known as Local Problem Solving. When communities are engaged in planning and implementing solutions, their efforts will be last and sustain over the long term. Through CCD resilience of members in the communities can be enhanced to the face the hardship including as natural disasters, economic difficulties and social shifts.

Through CCD communities are advocated for their rights and they will be educated how the policies affect them. Through their successes and failures communities learn and evaluation on regular basis assist them to alter their strategies and learn from the mistakes they did. CCD, always respect the cultural norms in the particular geographical areas. That is essential to achieve sustainable development [1].

a) Sustainable Development

Sustainable development gained global recognition with the publication of the "Brundtland Report" in 1987 by the World Commission on Environment and Development. This report, titled "Our Common Future," laid the foundation for international discussions and agreements on sustainability,

including the United Nations' adoption of the Sustainable Development Goals (SDGs) in 2015 [2].

Overall, sustainable development seeks to create a world where economic, social, and environmental dimensions thrive harmoniously, fostering a prosperous and equitable future for all while respecting the limits of the planet's resources.

Sustainable development is ‘an approach to societal progress that aims to meet the needs of the present without compromising the ability of future generations to meet their own needs. It involves integrating economic, social, and environmental considerations to achieve balanced and lasting development’ [3].

Key aspects of sustainable development include environmental Conservation which emphasizes responsible stewardship of natural resources and ecosystems to prevent environmental degradation and ensure their availability for future generations. The other aspect is economic prosperity. Sustainable development seeks to promote economic growth and prosperity while considering the long-term impacts on communities and society as a whole. It involves fostering inclusive economic systems that benefit everyone. Social equity is another aspect. This approach prioritizes social justice, human rights, and equitable access to opportunities, resources, and services. It aims to reduce inequalities and address the needs of vulnerable populations.

Cultural Preservation aspect recognizes the importance of cultural diversity and heritage, encouraging the protection and preservation of cultural practices, identities, and traditions. Interconnectedness acknowledges the interdependence of environmental, social, and economic systems, advocating for integrated strategies that account for the interactions between these dimensions.

Long-Term Perspective highlights a future-oriented approach, considering the impacts of present decisions on future generations. This involves making choices that ensure the well-being of current and future societies. Precautionary Principle advocates that preventive action in the face of uncertainty to avoid potential harm to the environment or society.

Innovation and Technology encourages the development and adoption of innovative technologies and practices that contribute to environmental protection and societal well-being. Participatory Governance promotes inclusive and participatory decision-making processes that involve various stakeholders, including communities, governments, businesses, and civil society.

a) Sustainable Development Goals (SGD) and CCD

There is specific SGD’s that are aligned to achieve community capacity development of the local community. They are Goal 1; End poverty in all its forms everywhere, Goal 5: Achieve gender equality and empower all women and girls, Goal 8: Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all, Goal 10: Reduce inequality within and among countries and Goal 17: Strengthen the means of implementation and revitalize the global partnership for sustainable development.

b. One Villege One Product (OVOP) in Japan and lessons lerant from their approach

OVOP is a rural development approach that originated in Japan. It aims to promote local economic development by identifying and developing unique products or services from each village or community. The OVOP concept was developed by Professor Morihiko Hiramatsu at the University of Tsukuba in Japan in the late 1970s [6]. It has since been adopted and adapted in various countries around the world as a means of boosting rural economies and preserving local cultures.

The basic idea behind OVOP is to identify a distinctive product or service that a particular village or community can produce, often capitalizing on the area's natural resources, traditional skills, or cultural heritage. The goal is to create a sustainable local economy by nurturing and promoting this product, thereby improving livelihoods and stemming rural migration to urban areas.

Each community engages in a process of identifying a product or service that is unique to their area and has the potential to be developed and marketed.

Then, the identified product is then improved in terms of quality, design, and value. This might involve incorporating modern production techniques, enhancing packaging, and meeting certain quality standards.

The entire process is community-driven. Local residents are actively involved in decision-making, production, and marketing efforts. This sense of ownership fosters community pride and commitment.

OVOP emphasizes the marketing and promotion of the chosen product. This can involve branding, participating in local and national fairs, establishing connections with distributors, and even exploring export opportunities.

Communities often receive support and training to enhance their skills in production, marketing, financial management, and entrepreneurship.

OVOP projects often integrate traditional knowledge, skills, and cultural heritage, thus helping to preserve local traditions and ways of life.

By focusing on local resources and capacities, OVOP aims to create sustainable development that is both economically viable and environmentally responsible.

OVOP projects encourage collaboration between communities, regions, and even countries. This sharing of experiences and expertise can lead to innovative solutions and expanded markets.

In Japan, the OVOP approach has been particularly successful in revitalizing rural communities, boosting local economies, and preserving traditional craftsmanship. The concept has spread to other countries, including Thailand, Laos, and various African nations, where it has been adapted to suit local contexts and needs.

It is important to note that while OVOP can bring significant benefits, successful implementation requires careful planning, community engagement, and ongoing

support to ensure the sustainability of the chosen products and the well-being of the communities involved.

- *Development Goals Relationship*

Asset-Based Approach: Start by identifying the existing strengths, talents, and resources within the community. This could include the skills of individuals, local organizations, cultural assets, and community spaces. Building upon these existing assets forms a strong foundation for capacity development.

Participatory Approach: Involve community members in every step of the development process. Their insights, experiences, and aspirations should guide the planning, implementation, and evaluation of capacity-building initiatives. This not only empowers the community but also ensures that the solutions are tailored to their specific needs.

Skill Enhancement and Training: Provide training workshops and skill-building sessions that cater to the needs of the community. This could involve workshops on financial management, leadership, project management, communication skills, and more. The goal is to equip individuals with the tools they need to take initiative and lead positive changes.

Networking and Collaboration: Encourage networking among community members and organizations. Collaborative efforts often lead to innovative solutions and shared resources. This can be achieved through community events, forums, and online platforms.

Local Project Implementation: Encourage the community to identify and work on projects that directly address their needs. This could be anything from setting up a community garden to launching a literacy program. As community members actively engage in these projects, they learn valuable skills and develop a sense of ownership over their community's development.

Leadership Development: Identify and nurture emerging leaders within the community. Offer mentorship and leadership development opportunities to help them effectively guide community initiatives and inspire others.

Evaluation and Reflection: Regularly assess the impact of capacity-building efforts. What's working well? What could be improved? This ongoing evaluation helps fine-tune strategies and ensures that resources are being used effectively.

Sustainability: Ultimately, the goal is to create lasting change. Work towards ensuring that the capacity developed within the community can be sustained over the long term. This might involve passing on skills to younger generations, establishing mechanisms for ongoing learning, or embedding community capacity development within local institutions.

Advocacy and Empowerment: Equip the community with the knowledge and skills to advocate for their own needs and rights. Empowered communities are more likely to influence policy decisions and create an environment that supports their growth.

Celebration and Recognition: Celebrate achievements and milestones within the community. Recognizing and celebrating progress can boost morale and motivate community members to continue their efforts.

- *The Sustainable Development Goals (SDGs)*

The Sustainable Development Goals (SDGs), also known as the Global Goals, were adopted by the United Nations in 2015 as a universal call to action to end poverty, protect the planet, and ensure that by 2030 all people enjoy peace and prosperity [7].

II. METHODOLOGY

This research is conducted using mix methodology approach. Study is conducted as desk research initially. Case study method is adopted with participatory observation method. Observation and participatory research are being conducted in a long period in Oita prefecture of Japan. There are several locations and projects spread throughout Japan. Learnings from successful Japanese case study of One Village One product and it learning can be directly apply to Sri Lanka for community capacity and social development. Continuous training on conducting capacity development programs will be conducted among the selected communities.

III. RESULTS AND DISCUSSION

The areas which have been selected to conduct the research is Ambalangoda. 'Mask making' is a popular tradition in Ambalangoda area. 'The authentic Masks and Masking Traditions of Sri Lanka are extra ordinary culture phenomenon and a significant contribution Sri Lanka has made to the Asian Cultural spectrum' There are traditional artisans carry out their trade in the South-Western Province in Sri Lanka. Some artisans carried out this trade at a large-scale business whereas some carry out the trade as medium and small level. There is a Ambalangoda Mask Workshop and Museum is Sri Lanka, privately owned Museum managed by an institution named "Ariyapala and Sons, in order to strengthen this particular cultural heritage. There is a museum, workshop and a small library in this museum premises [9]. These masks have a very good market, in this area. Mask are sold to foreigners as well as to local customers. Also, mask dancing shows are organized to make a living by manufacturers. There are different kinds of employment opportunities created by the mask industry. Mask makers and painters, Kaduru tree suppliers, painting material suppliers, craftsmen, sellers, masks dancers, tourist guides and shipping lines are the major jobs created through this trade.

There are many issues identified in this trade by observing and after interviewing the traders and people in the area. Most of the makers do not have knowledge to market their products and earn. They still use traditional methods of selling. There is no value addition created as Japanese production and selling philosophies. Hence, it is evident that by following the CCD this industry can be developed.

The key dimensions of CCD can be employed regarding this. People engaged in the mask industry can be empowered more by providing know how to market them

internationally. The main ingredients or the factors of development and social capacity development will depend on Participation, asses- based approach, collaboration and networking, enhancing skills and training, local problem solving, ownership and sustainability, building resilience, advocacy and social change, evaluation and learning and cultural considerations.

IV. Conclusions and Recommendations

It can be concluded that mask industry in Ambalangoda can be developed through techniques in the CCD. This research study reveals many obstacles the community faces in engaging this mask trade. Most of the challenges can be overcome or mitigated through implementing CCD.

V. Prospective Study and Future Work

As suggested in order to overcome the hardship and challenges the community faces in the area, methods in CCD can be followed. For that more research should be done and more data should be collected using different data collection techniques.

It is expected to carry out the second phase of this research in order to gather more data and also, the researchers intend to provide solutions through following methods in CCD to address the issues the traders face in engaging in 'mask trade'. For that, it is expected to carry out a funded program in order to implement CCD in Ambalangoda area for Mask Traders in that area.

Acknowledgment

This research was supported by the vendors in Ambalangoda area by providing information.

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2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

Educational Attainment of Vedda Parents: A Study From Uva Province, Sri Lanka

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***Abstract*—Studies have highlighted poor educational attainment of indigenous communities compared to their non-indigenous counterparts. Veddas are indigenous people in Sri Lanka and there is a lack of research on their formal education. Hence, this study's main objective was to examine Vedda parents' educational attainment while considering their livelihood. This study forms part of a larger research conducted on science education of Vedda people in Uva Province, Sri Lanka from 2018 to 2021 employing a mixed methods research approach and an inductive convergent research design. The study collected qualitative data from 27 science lesson observations and 68 semi-structured interviews with parents (Vedda/mainstream), students (Vedda/mainstream), science teachers and Vedda leaders. Quantitative data obtained through 494 survey questionnaires distributed among science teachers, parents (Vedda/mainstream) and students (Vedda/mainstream). Results showed poor educational achievements of both Vedda and mainstream parents. Majority of mainstream parents (46.5%) had completed senior-secondary level, while majority of Vedda parents (47.8%) had only completed primary level. Further, 13.0% of Vedda parents and 4.3% of mainstream parents had not received any formal schooling. Reasons for lower educational attainment of Vedda parents found to be lack of awareness about formal education of their parents and resulting poor interest in motivating children towards formal education. It is worth noting that the primary source of income for both groups was agriculture, only a minority engaged in government or private sectors. Lower educational attainment could be a reason for above finding. Hence, relevant measures are crucial to enhance educational attainment of Vedda parents and their mainstream counterparts.**

Keywords—Indigenous communities, educational attainment, Vedda parents, mixed methods research

I INTRODUCTION

Educational attainment is the highest level of education that an individual has fulfilled [1]. Educational attainment enhances active participation in society. Educational attainment also affects employment and poverty [2]. Literature shows inequalities in educational attainment between rural and urban people in which rural individuals have low educational attainment compared to urban counterparts [3]. Further, a disparity in educational attainment can be seen among indigenous people and non-indigenous people where indigenous people show a lower educational attainment in contrast to the general population [4].

Indigenous people are those who consider themselves distinct from the mainstream societies that currently exist in their historical territories [5]. The concept of indigenous can be understood concerning priority in time, the continuous cultural distinctiveness, self-identification and recognition of state authorities and others as a distinct group, and experience of oppression [6].

Indigenous people of Sri Lanka are called Veddas. The ancestry of Veddas dates back to nearly 30,000 years, millennia before the arrival of Aryans (Indian settlers) in Sri Lanka 2,500 years ago. Further, there are studies that show Veddas are the descendants of Balangoda Manavaya (*Homo sapiens balangodensis*), early hunter-gatherers from about 16,000 BC or possibly much earlier [7,8,9,10]. Initially, they were found throughout the island but now confined to a limited area known as Vedi Rata or Maha Vedi Rata from Hunnasgiriya mountains to lowlands down to the sea in the east. Vedda settlements can be found in Dambana, Rathugala, Henanigala, Pollebedda, Dalukana, Anuradhapura, Panama, Muttur, and Vakarai at present. These settlements are spread in Uva Province, Eastern Province, and North Central Province of Sri Lanka [8,10,11].

Vedda people are also considered under compulsory education in Sri Lanka. Even though formal education was introduced to Vedda people about fifty years ago [8] and Vedda children also learn at schools alongside mainstream students, there are only a limited number of studies that give insights into the interaction between Vedda people and formal education including their educational attainment. Hence, the main objective of this article is to examine the educational attainment of parents of Vedda students in two selected Vedda settlements in contrast to their mainstream counterparts. Further, this article paid attention to the livelihood of Vedda parents and mainstream parents as livelihood is related to educational attainment.

II METHODOLOGY

In order to achieve the above objective this article presents data collected from a larger study conducted on the science education of Vedda people in Uva Province, Sri Lanka from 2018 to 2021. Parents of Vedda and mainstream secondary-level (Grades 6 to 11) students of three selected schools adjacent to two well-established Vedda populations in Uva Province were considered in this study.

The above study employed a mixed methods research approach with an inductive convergent research design. Hence, both qualitative and quantitative data were collected.

Qualitative data were collected from 27 science lesson observations (23 minutes on average per lesson) and 68 semi-structured interviews conducted with Vedda parents, mainstream parents, Vedda students, mainstream students,

science teachers of the selected schools and Vedda leaders/ senior community members.

Quantitative data were collected by 494 survey questionnaires from Vedda parents (N=23), mainstream parents (N=187), Vedda students (N=41), mainstream students (N=235) and science teachers (N=8). Questionnaire data were collected predominately using Likert items. Data on the educational attainment and livelihood of the parents were collected through two multiple-choice items in the questionnaire administered to the parents. Qualitative data were analysed thematically [12,13] whereas the quantitative data were analysed descriptively. Finally, the convergent analysis (integration of results) was conducted by directly comparing the qualitative and quantitative results (Fig. 1).

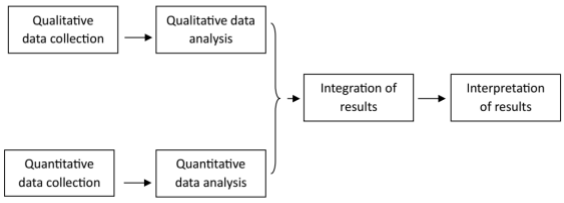

Fig. 1. Research design of the study

III Results

The convergent analysis resulted in five shared themes and two unique themes. The five shared themes were view towards general education and science learning, support towards general education and science learning, challenges for science teaching and learning, suggestions to enhance science learning of Vedda students and mainstream students, and socioeconomic factors of parents. The unique themes were, good interaction between Vedda students and mainstream students and poor concern of authority on education of Vedda people. Findings on the educational attainment and livelihood of parents were found under the shared theme "socioeconomic factors of parents" and those findings are discussed in this article.

Quantitative data showed 47.8% of the Vedda parents had studied up to Grade 5. There were 26.1% educated up to G.C.E (O/L). Only 8.7% were educated up to the G.C.E. (A/L). Further, 13.0% of Vedda parents had no school education (Fig. 2).

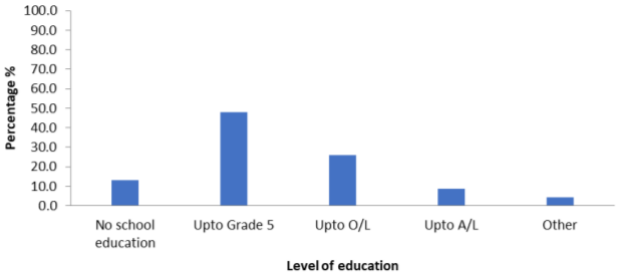

Fig. 2. Educational attainment of Vedda parents

In terms of the mainstream parents, 46.5% had studied up to G.C.E. (O/L) and 13.5% had studied up to G.C.E. (A/L). There were 4.3% of mainstream parents who had no school education and only 1.6% of mainstream parents had an education up to a basic degree level (Fig. 3).

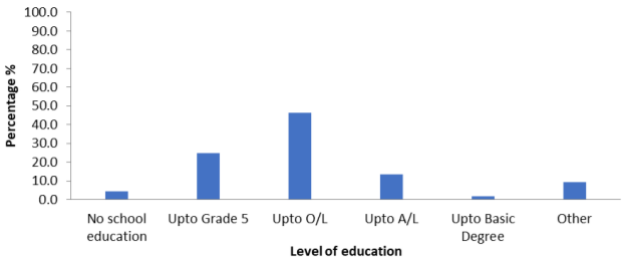

Fig. 3. Educational attainment of mainstream parents

Qualitative results depicted that there were Vedda parents who had no school education. A Vedda father and a Vedda mother responded, "I have not attended" (fieldnote 30.01.2020) and "No, I did not" (fieldnote 28.01.2020) respectively when they were asked about their school education. Another Vedda mother said that "No, I have not" (fieldnote 28.01.2020) when she was asked whether she had a school education.

Qualitative results provided evidence for Vedda parents having different levels of educational attainments. One Vedda father replied, "Up to five" (fieldnote 30.01.2020) when he was asked about his school education. Another Vedda mother mentioned, "I studied up to Grade 5" (fieldnote 28.01.2020). A different Vedda mother said, "I have studied only up to Grade 4" (fieldnote 28.01.2020). One Vedda mother mentioned, "I had attended school up to Grade 10" (fieldnote 30.01.2020) A different Vedda father responded, "I have attended school up to Grade 11" (fieldnote 15.08.2019).

Qualitative results represented reasons for poor attainment in the education of some Vedda parents. One Vedda parent said, "The reason is that our parents are indigenous. Therefore, they did not think of it [educating children] that much in those days. There was not much interest those days and they have not sent us to school" (fieldnote 28.01.2020).

One Vedda mother replied, "A, I could not do O/L. Even though I went to Grade 11, my mother got sick three months before O/L. So, because of that, my education got crippled" (fieldnote 30.01.2020). One Vedda leader stated, "When we were children we did not have a school to learn and there was nothing like a town" (fieldnote 28.01.2020).

Qualitative results also showed evidence for different levels of educational attainment of mainstream parents. Except for a few, the majority of the mainstream parents had educated at least up to the G.C.E. (O/L). Apart from that, there were some parents who had learnt up to the G.C.E. (A/L). One mainstream mother said that "I went to several schools. I did O/L at Atampitiya school" (fieldnote 10.02.2020). Another mainstream mother responded that "I went to the school "B". I did O/L. I was there in the A/L class one year but I could not sit for the exam" (fieldnote 10.02.2020). A mainstream father mentioned, "I am Priyantha. I learnt only up to O/L. I attended this "C" secondary school [school C]" (fieldnote 17.02.2020). Another mainstream mother responded, "I am from Wadinagala. I went to the same school from grade one to A/L. I did A/L in arts stream" (fieldnote 17.02.2020).

Qualitative results also presented reasons for poor attainment in the education of some mainstream parents. One mainstream mother mentioned, “There were financial problems. Our parents were not keen on our education as much as we do today for our children. There were financial problems. That was why I dropped out” (fieldnote 10.02.2020). Another mainstream mother said that she was interested in sports rather than education, “Lack of my interest. I liked sports” (fieldnote 10.02.2020). A different mainstream mother mentioned that “There was no opportunity for us to go for an extra class those days and even the teachers were not there continuously” (fieldnote 17.02.2020).

According to the quantitative results 78.3% of the Vedda parents involved in agriculture. Further, the proportions of Vedda parents employed in the government sector and private sector were 4.3% in each sector (Fig. 4).

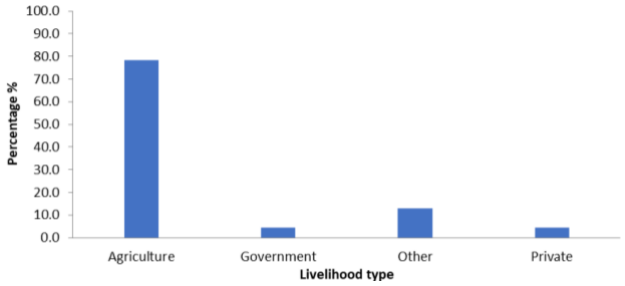

Fig. 4 Livelihood of Vedda parents

In contrast, 62.9% of the mainstream parents depended on agriculture (62.9%). There were 13.7% and 5.7% of mainstream parents who were involved in the government sector and private sector, respectively. Further, a proportion of 17.7% mainstream parents were employed in “Other” category (Fig. 5).

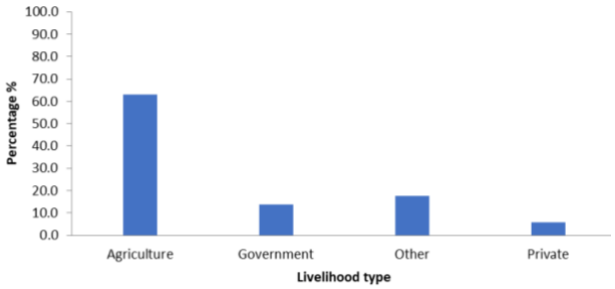

Fig. 5. Livelihood of mainstream parents

Qualitative findings provided evidence for the agricultural livelihood of the Vedda parents. One Vedda parent said that “We do chena cultivation [shifting agriculture], my husband does not do a government job, neither I. both of us do farming. So, when it takes farming and the cost for three children. The economy is for everything” (fieldnote 30.01.2020). Another parent mentioned, “We grow mung and cowpea. We also grow maize” (fieldnote 28.01.2020).

Evidence for other type of livelihoods also collected through qualitative data. One Vedda mother responded, “So, I work for hire, so, I earn 700 rupees [LKR 700] per day. From that, I have to buy food for them [her children] and also books for them” (fieldnote 28.01.2020). One Vedda mother stated, “I am working in this boutique and father is working for hire [as a labourer]” (fieldnote 28.01.2020).

Qualitative data showed evidence for Vedda parents working in the government sector as well. A Vedda mother said, “He [husband] works in the Civil Defense Force” (fieldnote 28.01.2020).

IV Conclusion

Quantitative data and qualitative data showed that the educational attainment of both parent groups was relatively poor. The above finding confirms the gap in educational attainment between rural and urban populations as the study was conducted in rural Uva Province.

However, the educational attainment of Vedda parents was lower than mainstream parents. The majority of mainstream parents had completed senior secondary level (46.5%) at school whereas the majority of Vedda parents had completed the primary level of school education (47.8%). Further, a higher proportion of Vedda parents (13.0%) had not received a school education compared to that of the mainstream parents (4.3%).

The above findings are parallel with the existing literature on the educational attainment of Vedda people. According to [8] the attainment of Vedda students in general education was extremely poor. Only eight members of the community had degree-level qualifications.

The reasons for the poor educational attainment of Vedda parents could be unawareness of their parents of the formal education and the resulting poor interest in motivating their children towards formal education. On the other hand, poor financial status of parents, lack of interest of students, lack of relevant learning opportunities and teachers could have resulted in poor educational attainment of mainstream parents. The poor financial situation could have been a decisive factor in the low educational attainment of Vedda parents as well.

Results show that the majority of the Vedda parents are not educated above the primary level. Hence, it is likely that Vedda children could not get enough academic assistance from their parents. Academic assistance from parents is important for students to navigate through the learning process. Moreover, due to the poor education level of parents, Vedda children would have to rely on their school teachers or additional learning opportunities like extra tuition classes.

Quantitative results showed that the most common source of income of both groups of parents investigated in this study was agriculture. Apart from that, a minority of parents were involved in the government sector, private sector, and other types of occupations. The percentage of Vedda parents involved in a government sector occupation or a private sector occupation was relatively less compared (8.6% in both government and private sectors) to mainstream parents. It could be assumed that the lower educational attainment of both parents resulted in the above findings as education impacts employment [14]. Therefore, a lower level of education leads to diminished livelihoods, making it challenging to educate the next generation. Consequently, this could lead to a cycle of lower educational levels in subsequent generations.

It could be suggested that more Vedda communities and their counterparts need to be studied to get a general idea of

their educational level and livelihood and the necessary actions required to be taken to develop the above aspects, especially with an understanding of the Vedda culture.

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2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

Food Consumption Patterns among Undergraduates: Evidence from the Faculty of Arts, University of Peradeniya

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***Abstract*—Understanding youth's food behaviors is essential for preventing health issues, promoting lifelong health, and advancing sustainability. This study delved into the food behavior of students at the Faculty of Arts, University of Peradeniya, using a mixed-method research design. We sampled 250 students via stratified random sampling, collecting quantitative data through survey questionnaires and qualitative insights through four focus group discussions. The data were analyzed using descriptive statistics and thematic analysis. Our findings revealed significant associations ($p < 0.05$) between monthly food expenses and residence location, which impacted food satisfaction during university life. Notably, students in university hostels allocated more money to food compared to those in private boarding houses or living off-campus. Communal eating practices, especially between main meals, were linked to higher food expenditures among undergraduates. Gender disparities in food purchasing habits emerged, with more female students in university hostels consuming canteen foods due to limitations in access to food outside. However, frequent hostel canteen users expressed higher levels of food dissatisfaction than faculty canteen users. While no significant gender-based relationship with meal skipping was observed, lunch was the most commonly missed meal for both genders, often due to time constraints and financial limitations. These findings highlight the influence of living context and socio-economic factors on students' eating behaviors. Researchers and policymakers can utilize this understanding to foster healthier diets among university students. Targeted interventions, such as enhancing on-campus dining facilities to offer affordable, diverse, and healthy food options, and providing financial support, can foster a positive food culture at universities.**

Keywords—Dietary practices, eating behavior, food expenditure, meal skipping, undergraduates, Sri Lanka

I. INTRODUCTION

In the field of medical sociology, health is defined as the holistic well-being of an individual, encompassing their physical, mental, intellectual, social, and spiritual dimensions [1]. While numerous elements influence one's state of good health, socio-cultural aspects related to an individual's dietary choices play a pivotal role in determining their health. Consequently, a person's eating habits undergo transformations influenced by a multitude of factors, including age, gender, educational background, ethnicity, income, as well as environmental and cultural influences [2]. The progress of any nation or society is contingent upon the comprehensive physical and psychosocial well-being of its youth population, as they constitute the vital workforce driving this advancement. Within this youth demographic, students pursuing higher education, particularly university students, hold a prominent and vital position.

Understanding undergraduates' food behaviors is essential for promoting lifelong health, preventing health issues, and advancing sustainability. Therefore, this study delved into the food behavior of students at the Faculty of Arts, University of Peradeniya. The dietary choices and habits of university students are of particular interest due to their formative role in shaping lifelong health practices and their potential impact on broader sustainability goals. Moreover, as undergraduate students are at a critical stage in their lives where habits and behaviors are established, investigating their eating behaviors can shed light on key factors influencing dietary choices [3]. Furthermore, this research can help design targeted interventions to encourage healthier and more sustainable food choices. The specific focus on students at the Faculty of Arts, University of Peradeniya, offers valuable insights that may inform policies and practices within the academic community and beyond.

However, limited sociological research has been conducted in Sri Lanka on the food behavior of the young population, such as university students. This knowledge gap makes it imperative to explore the food behaviors and eating patterns of this demographic, particularly within the unique context of Sri Lanka, where socio-economic, cultural, and environmental factors significantly influence food choices. Therefore, this study aims to investigate students' food behavior, their attitudes toward food choices and eating patterns, as well as the challenges they encounter when fulfilling their nutritional needs during university life.

II. METHODOLOGY

This study employed a mixed-method research design to investigate the food behavior of 250 students at the Faculty of Arts, University of Peradeniya. Participants were selected through stratified random sampling to ensure representation across different academic years, with their voluntary participation.

Quantitative data were collected through structured questionnaires, focusing on food behavior, and socio-economic conditions. Additionally, we conducted four focus group discussions to gather qualitative insights into the factors influencing students' food choices. Quantitative data underwent descriptive statistical analysis using Statistical Package for Social Sciences (SPSS-22), while thematic

analysis was applied for qualitative data. Throughout the study, research ethics were maintained, and data privacy and confidentiality were upheld, respecting the voluntary participation and the option to withdraw from the study the respondents

III. Results

A. Food Behavior of the Undergraduates

This study revealed that the average monthly expenditure on dietary needs by students in the Faculty of Arts is approximately LKR 10,600. Furthermore, it found no significant difference in food expenditure between genders. However, female students exhibit a higher level of attention to their dietary choices compared to males. Additionally, the Analysis of Variance (ANOVA) test results indicated a statistically significant relationship ($p<0.05$) between students' food expenditure and their place of residence. Tab. 1 shows that students residing in university hostels allocate more funds for their food consumption compared to those in private boarding houses or living off-campus.

Table 1. Monthly Food Expenses By Residence

Place of residence	Monthly food expenditure)Rs.(
University hostels	11555.75
Boarding houses	10279.74
own house	5813.98
At a relative's house	4667.67

[a]Field data. (*2023*)

The study's findings demonstrate that monthly food expenditures are notably higher among students residing in university hostels, particularly among females. The following qualitative data shed light on the reasons behind this trend "Previously, students were able to cook their food inside the hostel room or in the common kitchen. However, this practice was discontinued due to the high cost of electricity bills. Consequently, we now have to purchase food from the hotel canteen, which we find doesn't provide good value for the money spent. When we could cook, we could prepare one-pot meals and eat adequately. However, with the current arrangements, even the portion size is insufficient. We feel hungry again after a few hours and end up spending money on snacks or quick eats. As a result, our overall food costs have increased, and we need to think twice before eating, even when we are hungry" (3rd-year, female student).

Furthermore, qualitative data revealed that communal dining habits and social interactions within university hostels contribute to the increase in food expenditures to some extent. Additionally, a noticeable pattern emerged concerning the relationship between one's place of residence and food expenditure. Correlation analysis indicated a moderate negative correlation (Pearson Correlation -0.282 & $P<0.05$), suggesting that as the distance from the faculty to the residence increases, monthly food expenses tend to decrease. This phenomenon can be attributed to the diminishing sense of social interaction and camaraderie associated with the university as one moves farther away from the campus. This observation aligns with theoretical perspectives within sociology, including the concept of conspicuous consumption. According to this notion, individuals make consumption choices not solely driven by practical needs but also influenced by their social environment [4]. It is evident that the vibrant social atmosphere on the university campus substantially influences students' food expenses.

B. Gender Differences in Food Purchasing Habits

Another intriguing discovery emerged from the chi-square test, revealing that female students exhibit a higher tendency to use hostel canteens compared to their male counterparts. This preference may be attributed to the limited access female students have to off-campus dining options, leading them to opt for the most accessible choice. Such a situation is primarily a consequence of the challenges that hinder female students from frequently exploring beyond the university campus, particularly due to concerns related to safety and transportation. Fig. 1 illustrates the gender-based food purchasing patterns.

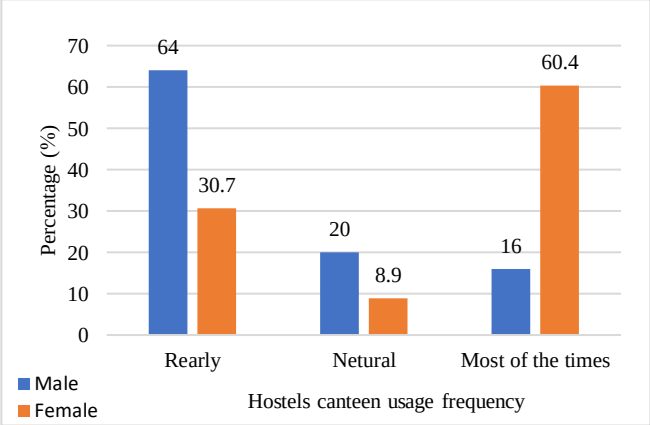

Fig. 1. Food purchasing patterns by gender

Additionally, this study has uncovered a substantial contrast in food satisfaction levels among frequent canteen users. This contrast is visually represented in Fig. 2, which displays the satisfaction levels of students who are regular patrons of hostel canteens.

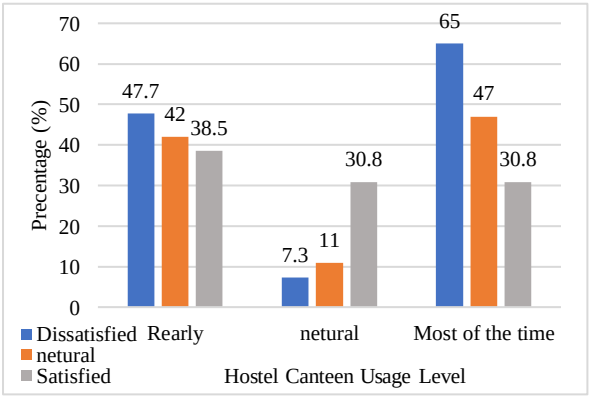

Fig. 2. Satisfaction levels among different categories of hostel canteen users

The chart clearly illustrates a considerable 65% dissatisfaction rate among individuals who frequently dine at

hostel canteens. Expanding on the earlier analysis, it becomes evident that a notable level of food dissatisfaction is prevalent among those who regularly consume canteen food. Importantly, this group predominantly comprises female students. Consequently, it can be inferred that female students who are frequent customers of hostel canteens experience a pronounced degree of food dissatisfaction. This aligns with research on gender disparities in food access and food security, where women often face challenges related to access, affordability, and quality of food. The dissatisfaction rate among regular canteen users underscores the limitations faced by female students in terms of food access and quality. These findings are consistent with sociological discussions on food inequalities and the social determinants of food security.

C. Meal Skipping Patterns Among University Students

A well-established body of prior research consistently underscores the prevalence of meal skipping as a prominent behavioral trend among university students, a phenomenon reaffirmed by the findings of this study [5]. These results illuminate the tendency among students to skip breakfast and lunch more frequently, with dinner being the least skipped meal. Consequently, the primary determinants of meal skipping appear to revolve around issues related to effective time management, compounded by financial constraints.

Notably, these findings also reflect the adverse impact of Sri Lanka's prevailing economic challenges on university students, where the ability to maintain regular meal schedules is notably affected. However, it is essential to highlight that, according to the Mann-Whitney U test analysis, while a correlation between gender and meal skipping emerged, it is equally vital to emphasize the absence of a statistically significant relationship ($P>0.05$). Hence, the factors influencing meal-skipping behavior are observed to be consistent across all students within the faculty.

IV. Conclusion

The findings of this study shed light on the food behaviors of undergraduates within the Faculty of Arts, adding to the growing body of sociological research on food consumption patterns and their implications. Several significant aspects related to food behavior, expenditure, and sociocultural factors are highlighted, prompting comparisons with analogous studies in different contexts to deepen our understanding of the sociological implications.

A consistent theme resonating with existing research is the influence of economic challenges on food expenditure. The average monthly expenditure of LKR 10,600 serves as a poignant indicator of the financial constraints students encounter. This echoes findings from diverse settings, such as studies involving college students in Western nations, where economic limitations frequently lead to reduced food budgets [6]. It is evident that the economic landscape significantly shapes the dietary behavior of university students, emphasizing the universal impact of financial considerations on food choices.

Moreover, the research illuminates the substantial impact of students' living circumstances and socio-economic factors on their dietary habits. These insights have far-reaching implications for both researchers and policymakers, providing a foundation for enhancing the dietary practices of university students and promoting their overall well-being.

Primarily, this study underscores the paramount importance of tailored interventions designed to cultivate a healthier food culture within university environments. Offering accessible, diverse, and nutritionally balanced food options within on-campus dining facilities is pivotal in encouraging healthier eating habits among students. These initiatives not only cater to the diverse needs and preferences of the student body but also create an environment where making nutritious food choices is convenient and appealing.

Furthermore, recognizing the financial constraints that many students grapple with, providing financial support or assistance programs can alleviate the burden of food expenses. This approach further contributes to fostering a positive food culture by ensuring that students have access to the essential resources required for maintaining a balanced diet.

In summary, this research provides valuable insights into the intricate interplay of factors influencing students' dietary behaviors. By implementing policies and initiatives that account for the living context and socio-economic considerations of university students, it is possible to cultivate a food culture that supports their well-being and holistic development. These efforts can yield enduring benefits for the health and sustainability of university communities, ultimately leading to more informed dietary choices and an elevated quality of life for the students.

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2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

The Role of Artificial Intelligence in Teaching English as a Second Language in the Higher Education Sector: A Systematic Literature Review

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***Abstract*—Artificial Intelligence (AI) has ushered a transformative era in language learning, making it more dynamic, personalised, and accessible than ever before. This study is focused on the rising roles of AI in higher education, mainly focusing on its applicability on Teaching English as a Second Language through a methodical evaluation of the existing literature. Data were gathered via a systematic review of existing scholarly articles published in Scopus and the Web of Science databases for academic research from 2018 to 2022. The review followed a systematic inclusive and exclusive qualitative research methodology by prioritising articles on language learning and teaching, course/program assessments and applications. The findings demonstrate the enormous contribution of AI on the quality of educational services, hands-on learning and teaching, teaching assessment methods and pedagogical implications. According to the study, AI will likely have an impact on language learning mostly through self-regulated aspects. As a result, higher education institutions should integrate AI into different aspects of teaching and learning in order to offer innovative ways to enhance the language learning process, necessitating a balanced approach to ethical and instructional considerations.**

***Keywords*—Artificial intelligence (AI), teaching english as a second language, assessments, pedagogical implications**

I. INTRODUCTION

The role of Artificial Intelligence (AI) in Teaching English as a Second Language (TESL) has emerged as a transformative force in the field of language education. With the increasing demand for English proficiency worldwide and the rapid advancements in AI technologies, the integration of AI tools and platforms has opened new horizons for both educators and learners. This symbiotic relationship between AI and TESL instruction is reforming language learning, making it more adaptable, efficient, and engaging than ever before. (Chen et al. [1]). In this dynamic landscape, AI is not just a tool; it is a catalyst for fostering English language proficiency in diverse, global contexts. AI is increasingly playing a significant role in TESL by providing innovative tools and resources that enhance the language learning process. Most importantly, AI plays a significant role in transforming Learning Management Systems (LMS) to enhance the overall teaching and learning experience.

A. The Future of LMS-based Language Learning

The role of the LMS has been changing and is now seen as a tool that supports both the user and the administration across a range of contexts, whereas the traditional LMS was conceived just as a tool which supported the university education and administration. However, the next generation is much more concerned with the increased ability for these platforms to introduce more cognitive services, such as AI to assist both educators and students in the practice of teaching and learning.

These features are more aligned with modern learning design approaches centered on the 'learner experience,' which then complemented by the basic provision of communication and assessment tools powered by AI to offer more personalized, accessible language instruction, while learners benefit from tailored lessons, interactive experiences, and real-time feedback (Zou et al. [2]). This is seen very clearly in the recent advent of ChatGPT from Open AI, which has carried the whole learning and teaching experience to the next level.

Furthermore, AI will enhance the administrative efficiency of LMS platforms. Routine administrative tasks, such as grading assignments, tracking student progress, and managing course materials, can be automated through AI. (Chen et al. [1]). From a learner's perspective, AI-driven LMS can provide instant feedback and recommendations. It can identify areas where a student may be struggling and suggest additional resources or activities for improvement. This immediate and targeted support can foster independent learning and a deeper understanding of the material through identifying learner gaps. Moreover, the AI powered LMS will provide interactive educational content by engaging in discussions with students and address their questions within seconds. This will address conventional classroom management issues to a great extent. (Aldahwan et al. [3]). However, while the role of AI in managing LMS is promising, it also brings challenges and ethical considerations. Issues related to data privacy, security, and the potential for bias in AI systems must be addressed to ensure equitable access and outcomes for all learners.

II. Literature Review

AI has a lot potential to expand and enhance teaching and learning significantly within the higher education sector. The literature on the role AI in TESL underscores the transformative potential of AI-driven solutions in language education. Researchers in language studies have recognized the imperative of integrating advanced intelligent technologies into e-learning systems. This integration is deemed essential for enhancing the overall quality of learning experiences, aiming to provide personalized learning content, automated guidance, instant feedback, and adaptive learning paths. (Tang et al. [4]; Am et al. [5]). Continuous practice and improvement in language skills have been emphasized in the studies by Liu et al. [6] and Zhang et al. [7] with AI-driven language learning resources enabling learners to practice and enhance their language skills in real-world contexts. These simulator environments will lay the basic foundation for the development of language skills without the initial interference of a teacher. As per Mikic´ et al. [8], "learning opportunities created through AI should not be designed in a vacuum; rather it should match learner needs and desires as closely as possible". As a result, AI-driven learning systems, developed using various intelligent methodologies, notably AI-based algorithms, intelligent agents, and data mining techniques, have proven to be successful in the implementation of personalized learner models (Zawacki-Richer et al, [9]). The learner models can address diverse learner requirements by recognizing various learner motivations, pre-existing knowledge, individual personalities, and learning behaviors, all of which can influence their educational journey. (Abyaa et al. [10]). As a result, furnishing personalized learning content to each learner is not just a choice but a mandatory requirement. The process of collecting and regularly updating information about a learner through clearly defined procedures will be beneficial in developing modeling approaches and techniques, incorporating both knowledge-based and behavior-based AI models. (Ajroud et al [11]). Confronted by traditional norms, a transitional strategy involves acquiring data on the extensive learning experiences of an individual or group, which can be gathered and synchronized with a multitude of learning activities across various platforms. (smith et al. [12]; Zapta-River. [13]. Hence, AI will undoubtedly improve the quality of education by catering to different educational practices, improving teaching and learners' academic performance. Santoso et al. [14] & Yang et al. [15], emphasise the importance of AI-driven feedback in language learning applications, specially in the spoken language arena specifying its importance in pronunciation development. The implementation of chat bots and virtual language assistants, discussed by scholars like Liu et al. [6], has made interactive language practice accessible to learners at any time by e-learning assistant systems. These tools offer opportunities for learners to engage in conversations and receive immediate feedback, which contributes to improved language skills.

Unlike the traditional assessing systems, where leaner performance is judged through a set of questions, AI will play a crucial role in optimizing language assessment and placement, ensuring learners are appropriately challenged. Furthermore, adaptive assessments efficiently determine a candidate's precise level of knowledge by narrowing down the scope of the learner's abilities. (Chrysafiadi et al. [16]; Krouska et al. [17]) Authors such as Chen et al. [1] have examined on how AI facilitates real-time feedback on various language aspects, including grammar, listening, and vocabulary usage by enhancing learners' language proficiency. This real-time feedback mechanism plays a critical role in improving learners' language proficiency and accuracy. Mousavinasab et al. [18] highlights the benefits of AI in providing personalized language assessing pathways which will be finally evalutaed through a common rubric system. Therefore, when integrated into various learning platforms, an adaptive e-learning system has the potential to provide personalized learning opportunities, contributing to improved learning quality and enhanced performance for learners. (Vanitha et al. [19]). As identified by (Shvets et al. [20]), a crucial aspect of e-learning involves ensuring that learners receive support and feedback consistently throughout the learning process. Moreover, as feedback is an essential part of assessments, the success of AI integrated learning models relies on the engaging experience and accurate feedback on learner performance (Hassan et al. [21]).

According to Chaudhry. [22], the utilization of AI applications in the classroom benefits both educators and students by facilitating collaborative learning and conducive learning environments. AI's data-driven insights provide educators and learners with a deeper understanding of progress, allowing for informed adjustments in teaching methods and content. Its data-driven insights enable both learners and educators to track progress and make informed decisions, ultimately transforming language acquisition into a dynamic, personalized, and effective way. Some examples of autonomous intelligent agent systems, such as eTeacher, involve monitoring the learning activities and performance of learners by delivering personalized content, whereas another instance is Mod-Knowledge, which analyzes learner interactions to assess their knowledge state. (Trifa et al. [23]). These studies collectively demonstrate that AI is playing an increasingly important role in TESL, offering innovative tools to educators and learners for achieving language proficiency and communicative competence. The personalized, real-time, and accessible nature of AI-driven language learning resources is shaping the future of language education while also bringing institutional challenges as well as disparities in the language learning process.

III. Methodology

In this research, a systematic review methodology was employed to gather data from existing scholarly articles related to AI published within the timeframe of 2018 to 2022. The primary sources of data included the esteemed

TABLE I
CATEGORICAL DISTRIBUTION OF RELATED RESEARCH

Category	Techniques with examples	References	Common findings/features
Language Learning and Teaching (LLT)			Adopts a personalized approach to meet the specific needs of each individual learner
1. Learner Modelling	1.1 Prediction (AL-TESL-e-learning system)	[24]	Support learners in developing a deeper understanding of the learning process
2. Knowledge Tracing	2.1 Deep Knowledge Tracing (Udacity)	[25]	Construct models by initially collecting data and continuously updating the learner model through ongoing tracking
	2.2 Autonomous Agents (e-teacher, Mood knowledge)	[23]	
3. Visualisation of Learner's data	3.1 Open leaner Model (Flexi-OLM, UM toolkit, CALMsystem)	[26, 27, 28]	Collects learner data through examinations, surveys, learner preferences, and the study habits, system activities, and processes of learners.
	3.2 Learning Analytical Dashboards (SCELE, iTutor)	[14, 29]	Through the data repository, learners can retrieve information about their existing knowledge levels, challenges in the subject area, and any misconceptions
4. Personalised Learning	4.1 Collaborative Filtering (peer Grade, LogCF)	[30]	
	4.2 Knowledge Based Filtering (ScholarLite)	[31]	
	4.3 Hybrid Techniques (MoodleRec)	[32]	
Assessments			The ability to monitor and analyse the progress continuously
5. Adaptive Assessment	5.1 Student ranking, evaluation and assessment (TrueSkill)	[33]	Suggest available improvement paths by analysing the current learner knowledge and performance
6. Automated Feedback	6.1 Textual Feedback (Quizbot)	[34]	
	6.2 Video Feedback (ASSET)		
Pedagogical Applications			Customized according to various factors like learners' pre-existing knowledge, preferences, habits, behavior, etc
7. Learner guidance	7.1 Pedagogical/ Conversational Agents (Notebook)	[35]	Extracts insights from the accessible repositories and enhances learner models
	7.2 Multi Agents (F-SMILE)	[36]	Facilitates decision-making during the learner enrollment process
	7.3 Intelligent Tutoring Systems		Enhancement of existing study programs and educational practices
			Encourages self-motivation in learning and delivers personalized guidance by identifying areas of weakness or points for improvement
			Improves learners' learning efficiency
			Adapt to the diverse capabilities of learners by providing learning materials based on the learner's proficiency level.

academic databases, Scopus and the Web of Science, renowned for their comprehensive coverage of peer-reviewed literature. The systematic review process involved a structured search strategy, encompassing specific keywords, Boolean operators, and search filters, ensuring the identification of articles that precisely matched the research criteria. The selection criteria for inclusion in this review were meticulously defined, focusing on articles published within the stipulated time frame and originating from higher education institutions. The data collection process followed a two-step approach: an initial screening based on the examination of article titles and abstracts, followed by an in-depth full-text review. Relevant data from each selected article, such as the publication date, the title, the authorship, key findings specifying the areas of language teaching and learning, assessment methods and other pertinent details were systematically extracted. The synthesis of the gathered data involved categorization and summarization of key themes, trends, and findings specifying the prominent researches who were involved in introducing the learner models related to AI. Moreover, ethical considerations were diligently observed in compliance with copyright regulations and ethical standards. The systematic review methodology applied in this study is instrumental in providing a robust foundation for the analysis of scholarly

articles on AI in higher education institutions during the specified period, as sourced from Scopus and the Web of Science.

The Tab. 1 demonstrates the research contribution for the categories mentioned, and it provides a broader understanding of the research conducted related to the fields of learning and teaching, pedagogical applications, and assessments

IV. Results and Discussion

The incorporation of AI in TESL has yielded significant research findings with profound implications for learning, assessments, and pedagogy. AI-driven language learning platforms have ushered in a new era of personalized and adaptive learning experiences. Research suggest that AI can analyze learner data to create tailored learning pathways, optimizing content and pace to suit individual needs. Real-time feedback on grammar, pronunciation, and vocabulary usage, another pivotal AI contribution that has demonstrated the potential to enhance language proficiency and accuracy in both spoken and written communication.

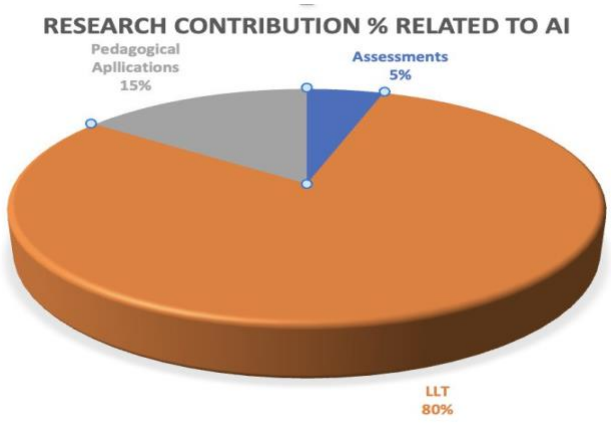

Fig. 1. Research contribution % related to AI

In the field of AI, there is a diverse landscape of research and application areas. Among these areas, Language Learning and Teaching represent a substantial focus, accounting for approximately 80% of AI-related endeavors as represented in the Fig. 1. Research conducted in this domain seeks to leverage AI technologies to enhance the overall learning experience. This includes the development of intelligent tutoring systems, adaptive learning platforms, and tools for automated content creation and recommendation.

In assessments, AI's role in evaluating language skills and placing learners in the appropriate courses or proficiency levels has also proven effective, ensuring that students are neither under challenged nor overwhelmed. Furthermore, AI's interactive tools, including chatbots and virtual language assistants, offer learners the opportunity for continuous language practice, with immediate feedback, ultimately contributing to improved conversational skills. However, research related to assessments constitutes nearly 5% of the AI-related work in the field as depicted in the Figure 1. AI has the potential to revolutionize assessment processes by offering automated grading, adaptive testing, and data-driven insights into student performance. However, research is focused on developing AI-based assessment tools and methodologies that can provide more accurate and timely evaluation of learners' knowledge and skills and this is still under continuous research.

According to the Fig. 1, Pedagogical applications encompass roughly 15% of the AI activities within the learning and teaching sphere. These applications involve the design and implementation of AI-driven teaching methods and strategies. AI-powered educational tools can provide customized learning pathways, track student progress, and offer real-time feedback. This, in turn, can optimize teaching methods, making them more effective and efficient.

These findings underscore the transformative impact of AI in TESL, offering innovative means to enhance language learning. However, while the advantages are clear, it is essential to recognize the associated challenges, including ensuring data privacy, addressing potential bias in AI systems, and providing educators with adequate training to effectively integrate AI tools into the classroom. As AI's presence continues to grow, the pedagogical implications in TESL shows more promising, engaging, efficient, and personalized language learning experience while necessitating a balanced approach to ethical and instructional considerations.

A. Potential Negative Outcomes

The integration of Artificial Intelligence (AI) into language learning has undoubtedly brought numerous advantages, yet it also carries potential negative outcomes that warrant careful consideration. One significant concern is the risk of over dependence on technology to experience holistic language learning methods. Excessive dependence on AI-driven tools can diminish the role of human interaction, cultural immersion, and emotional connection in language learning. Language is not just about vocabulary, grammar and writing; it's also about forming connections, understanding cultural nuances, and navigating real-world conversations, which AI may not fully replicate. Furthermore, AI's collection of vast amounts of learner data raises significant data privacy and security concerns. Ensuring the responsible and ethical use of this data is a challenge that must be addressed. AI systems, if not carefully designed, can inadvertently perpetuate biases in the content they generate or recommend, potentially reinforcing stereotypes. Technical limitations and inconsistencies in AI systems can also lead to frustrations and impede the learning process. The reduction of human interaction in AI-driven language learning platforms may limit the development of vital communication skills. In summary, while AI offers significant benefits in language learning, acknowledging and addressing these potential negative outcomes is essential to strike a balance between the advantages of technology and the rich, multifaceted nature of language acquisition.

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2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

A Literature Review on Customer Relationship Quality in Agile Projects in IT Industry

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***Abstract*—This research explores the intersection of Agile project management and Customer Relationship Quality in the Sri Lankan IT industry. Recognizing the pivotal role of project management in the industry's growth, the study emphasizes the significance of Agile methodologies in fostering customer-centric practices. A preliminary investigation, including discussions with industry professionals and a comprehensive literature review, reveals a notable challenge in IT companies: the struggle to enhance customer relationship quality in Agile projects due to a lack of understanding of essential aspects. Drawing on Social Exchange Theory, the research identifies a gap in understanding customer relationship quality dynamics within Agile frameworks, particularly in developing countries. The study formulates a problem statement addressing poor customer relationship quality in Agile-practicing IT organizations in Sri Lanka. The research's importance lies in its focus on the dynamics of customer relationship quality within Agile projects, offering insights to empower organizations in customer engagement, relationship cultivation, and value delivery. The findings underscore the need for a unified framework integrating critical success factors for both Agile projects and customer relationship quality. The conclusion highlights the future research agenda, emphasizing the exploration of common factors driving success in both domains. As the IT industry evolves, this research aims to contribute to a comprehensive understanding, enabling organizations to navigate complexities, optimize interactions, and achieve sustained success.**

Keywords—Agile project management, customer relationship quality, social exchange theory, IT industry

I. INTRODUCTION

In recent decades, the IT landscape in Sri Lanka has witness a remarkable growth by being the one of the key drivers of economic development. The growth of the IT industry and its importance cannot be overstated in today's digital age. For this success, project management plays a key role, by ensuring efficient and effective execution of projects.

Agile methodology has become a prominent and widely discussed topic in the IT industry [1]. Its popularity can be attributed to its flexible and iterative approach to software development [2]. The Agile methodology is closely associated with the Agile Manifesto, which acts as the cornerstone and guiding principles for Agile software development. Agile manifesto promotes customer relationship management of highest quality because agile project management is customer centric.

Customer Relationship quality plays a massive role in maximizing the outcome of a Project [3]. By maintaining a strong and effective bond with customers, any scale of a company can enhances customer satisfaction, engagement, and loyalty [3]. In project management, Agile methods stand out by putting a strong focus on building excellent relationships with customers. These methods emphasize collaboration and engaging practices [4], recognizing how crucial it is to involve customers in understanding and meeting their needs effectively. In Agile, customers are not just seen as onlookers but as essential contributors to the project team. Their viewpoints and feedback aren't just acknowledged but are valued and actively included. In Agile, working with customers isn't just a process; it's a partnership where their needs aren't just addressed but truly grasped.

II. METHODOLOGY

During the preliminary stage, we engaged in discussions with industry professionals to gain insights into their perspectives and knowledge regarding these factors. Additionally, we sought to understand how these aspects are applied in practical contexts.

Also, through an exhaustive examination of past studies, this preliminary study sought to identify areas where the current understanding is lacking or incomplete. By doing so, it aimed to highlight opportunities for further research, emphasizing the importance of addressing these gaps in both practical applications and theoretical frameworks. This preparatory phase sets the stage for conducting a meaningful and impactful research study. Following a systematic approach recommended by [5-8], the authors conducted a literature review to identify what existing literatures discussed regarding Customer Relationship Quality in Agile Projects. The study included English-language publications, specifically academic materials like peer-reviewed journal articles, book chapters, and conference papers published between 2012 and 2023.

TABLE I. ARTICLE INCLUSION CRITERIA

Characteristics	Inclusion Criteria
Types of Publications	Peer-reviewed journal articles, conference papers, book chapters indexed in Scopus
Language(s)	English
Time Period	From 2012 to 2023 (Inclusive)
Research Design	Conceptual and empirical
Content	studies that include discussions on Customer Relationship Quality
Source	Google Scholar

Google scholar was used for the search, resulting in 53,500 articles. The inclusion criteria were carefully defined (Tab. 1), and the search process followed a three-step

approach: identification, screening, and inclusion, as illustrated in Figure 1. The initial search focused on social exchange theory, guided by keywords such as "customer relationship quality" and "agile project management."

III. Findings

Through insightful discussions with industry professionals, it is clear that IT companies in Sri Lanka face a significant challenge when it comes to strengthening customer relationship quality in Agile IT projects. A prominent factor contributing to this issue is their limited understanding of the crucial aspects that should be considered in order to cultivate strong customer relationships. This lack of knowledge and awareness acts as a hindrance, impeding effective communication, collaboration, and the ability to meet customer expectations.

Also, Past research in this field has consistently emphasized the importance of "customer relationship quality" within projects, drawing upon the Social Exchange Theory [9]. However, these studies primarily focused on developed country contexts [9], neglecting the dynamics in developing countries. Additionally, there is a notable gap in addressing how customer relationship quality behaves within the Agile framework. Past research has primarily focused on investigating success factors individually for customer relationship quality and Agile projects. However, there has been a notable absence of research that comprehensively addresses the combined success factors for customer relationship quality in the Agile project context.

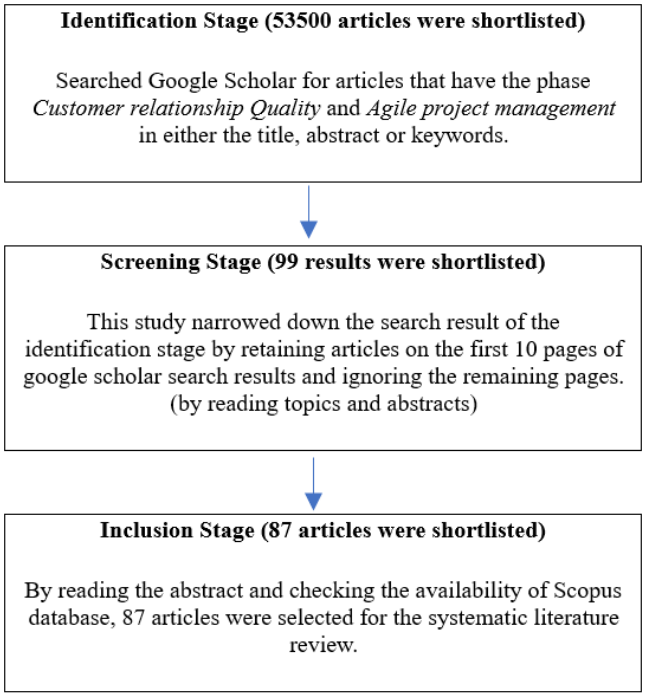

Fig. 1 . Article search process

A critical aspect left unexplored is the application of the Social Exchange Theory to Agile projects, particularly in understanding the cost-benefit relationship with customers, a key success factor in Agile endeavors. This highlights the need for further research to bridge these gaps and provide a more comprehensive understanding of the intricate dynamics between customer relationship quality, Agile methodologies, and diverse global contexts.

A. *Social Exchange Theory.*

Social Exchange Theory (SET) is based on one of the oldest ideas on human behavior [9]. According to [9], every interaction between people can be seen as an exchange of something valuable. Reference [9] came up with the term "theory of social exchange" to describe how people interact with each other. In this idea, individuals expect to get something, whether it's money or social rewards, when they engage with others. Reference [9] expanded this theory, saying that our social behavior is like a series of exchanges where everyone tries to get the most benefits. When someone helps us, we feel a duty to do something in return. SET focuses on the internal rewards and the trust between people, unlike economic exchange theory, which looks at external benefits and straightforward transactions [9].

Social Exchange Theory highlights the idea that social interactions involve trading intangible things with symbolic value. These things can be love, respect, knowledge, information, prestige, honor, and friendship [9]. People get into interactions expecting to gain these intangible advantages. Social Exchange Theory stands out from other theories because it emphasizes internal rewards and the importance of trust, offering a detailed framework to understand how people interact, why they exchange things, and what affects the quality of their relationships. In simple terms, Social Exchange Theory provides a unique perspective to explore the complex world of human interactions and relationships.

IV. Discussion

In Sri Lanka, there are numerous IT companies that engage with both internal and external customers who adopt Agile project management methodologies. Despite the customer-centric nature of Agile, it is regrettable that many Agile software projects, both in Sri Lanka and elsewhere, struggle to maintain satisfactory customer relationship quality. This issue is particularly evident within the Sri Lankan context, where poor customer relationships pose significant challenges and contribute to project failures. The underlying cause can be attributed to difficulties faced by IT companies in establishing and nurturing strong customer relationships. Therefore, it is crucial to recognize the vital role of effectively managing and cultivating customer relationships to ensure project success.

The social exchange theory provides insights into the determinants and dynamics of customer relationship quality, offering a framework to understand the factors that influence the quality of interactions and exchanges. Previous studies have explored the concept of customer relationship quality based on the social exchange theory in developed countries. However, there is a lack of research addressing this phenomenon in developing countries. Specifically, in the context of agile projects within the IT industry, there is limited understanding of the factors that drive customer relationship quality. This lack of research specifically addressing customer relationship quality factors in the context of agile projects in the IT industry highlights the need for a deeper theoretical understanding in this area.

Therefore, this research aims to fill this practical and theoretical gap by investigating and identifying the factors that influence customer relationship quality in agile projects in the IT industry, particularly in the context of a developing country.

Thus, the problem statement of the study can be formulated as follows,

*"**Poor Customer relationship quality in Information Technology Organizations that practices Agile project management methodologies."***

The research on "Determinants on Customer Relationship Quality in Agile Projects" holds a significance importance for both academics and industrial contexts. This study mainly focuses on understanding and analyzing the dynamics of Customer relationship quality within Agile projects, specially in the context of the IT Industry. By identifying these factors, this research aims to generate novel insights that can empower organizations to effectively engaged customers, cultivate robust relationships, and deliver solutions that truly and value.

Understanding the profound impact of customer relationship quality on project success and overall business performance is vital as it enables organization to tailor their practices and strategies to enhance customer relationship quality and foster lasting loyalty.

Additionally, this research has the potential to drive continuous improvement within agile methodologies by pinpointing specific areas where customer engagement and collaboration can be further enhanced. Also, this can provide valuable knowledge for project managers, teams, and stakeholders who has involved in IT projects. Overall, this research serves as an invaluable resource for organizations aiming to optimize customer relationships within agile projects in the IT industry, ultimately leading to superior project outcomes and sustained business growth.

V. Conclusion

In conclusion, this research has delved into the critical intersection of Agile project management and Customer Relationship Quality within the dynamic landscape of the IT industry in Sri Lanka. The findings underscore the challenges faced by IT companies in maintaining satisfactory customer relationship quality, despite the customer-centric nature of Agile methodologies.

The application of Social Exchange Theory (SET) has provided valuable insights into the determinants and dynamics of customer relationship quality, offering a nuanced framework for understanding the factors that influence the quality of interactions and exchanges. However, the research has also highlighted a significant gap in the current understanding, particularly in the context of Agile projects within the IT industry in developing countries.

Looking ahead, the future research agenda should focus on bridging this gap by exploring the common factors that contribute to the success of both Agile projects and customer relationship quality. While past studies have individually identified success factors for each aspect, a more comprehensive examination is warranted to uncover the shared elements that drive success in both domains. This holistic approach will not only enrich our theoretical understanding but also provide practical insights for organizations aiming to optimize their Agile practices and enhance customer relationships simultaneously.

Future research endeavors should aim to establish a unified framework that integrates the critical success factors for Agile projects and customer relationship quality. This approach will facilitate a more cohesive and synergistic implementation of strategies, addressing the challenges identified in this study. Moreover, by exploring these commonalities, researchers can contribute to the development of best practices that are applicable across diverse contexts, fostering a more universally effective approach to project management within the IT industry.

As the IT industry continues to evolve, there is a growing need for research that transcends individual facets of project management and customer relationships, seeking a comprehensive understanding of the interconnected factors that drive success. By focusing on the commonalities between Agile methodologies and customer relationship quality, future research can pave the way for a more integrated and effective approach to project management in the digital age. This, in turn, will empower organizations to navigate the complexities of the IT landscape, optimize customer interactions, and ultimately achieve sustained success in their projects and business endeavors.

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2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

Estimating Retail Price Movements of Upcountry Vegetables Using Time Series Analysis

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***Abstract*—It is essential to build a statistically equipped market information system and a comparative study to identify price fluctuations in upcountry vegetables. That systematic information on prices was important for producers, consumers, suppliers, the government, and international entities. This study aims to analyze retail price movements of upcountry vegetables and forecast prices using ARIMA time series techniques. Hence, this study used five main upcountry vegetables, including carrots, green beans, leeks, tomatoes, and beetroots, to evaluate retail price behavior. For this study, 13 years (2010–2023) of monthly wholesale prices were gathered. The best SARIMA models were ARIMA (1,1,1) (0,0,1) for carrots, ARIMA (2,1,1) (0,0,1) for beans, ARIMA (2,1,0) (0,0,1) for leeks, (1,1,2) (0,0,1) for tomatoes and ARIMA (1,1,1) (0,0,1) for beetroot.**

Keywords—*ARIMA, Up-country vegetables, Price fluctuation, SARIMA*

I. INTRODUCTION

Vegetables are perishables that have a price variation according to supply and demand. Vegetable prices directly impact residents' quality of life and farmers' income, which in turn influences the growth of Sri Lanka's vegetable sector and the country's overall economic balance. It is essential to forecast vegetable prices during both the harvesting season and the off-season for growers to make wise production decisions [1]. Forecasts of food commodity prices are essential for economic policy formulation, as agricultural price stability measures are crucial for breaking the vicious cycle of poverty and food insecurity in developing countries [2]. Inadequate availability of agricultural commodities results in price fluctuations and places a burden on consumers, whereas an excess of agricultural products leads to a decline in vegetable prices and causes financial setbacks for farming households [3]. Hence it is challenging for the government to create policies that adequately address the competing interests of farmers and consumers due to the imbalance in the supply and demand of agricultural products. Moreover, selecting a forecasting method to predict future prices will help policymakers and farmers to make the correct decision. Hence this study aims to analyze retail price movements of upcountry vegetables and forecasts of prices using ARIMA time series techniques.

The presence of price data on agricultural commodities aids private and public organizations in expanding their market. Commodity price analysis has made use of many forms of the autoregressive integrated moving average (ARIMA) model. The pricing behavior of nonperishable goods in South Asia has been studied using both simple and seasonal ARIMA models (SARIMA) [4]. This study used seasonal ARIMA models to predict up-country vegetable prices. The success of this decision-making affects the variation in the supply of food commodities and it ultimately results in price fluctuations.

Therefore, selecting a forecasting method to predict future prices will help farmers to make the correct decision. Understanding pricing patterns will help entrepreneurs make more informed decisions about their businesses and investments. The whole public as consumers benefit from the price information as well. Because agricultural products are essential for daily use, they constitute a significant portion of the market. The prices of these products have a substantial impact on both consumer spending and the income of agricultural households. [5]. The accuracy of the estimated price movements must depend on the quality and reliability of the data used and the appropriateness of the chosen forecasting model.

II. MATERIALS AND METHODS

The study made use of two-time series techniques such as Auto-Regressive Integrated Moving Average (ARIMA) and Seasonal Auto-Regressive Integrated Moving Average (SARIMA). This study involved the development of mathematical models to analyze the monthly prices of up-country vegetables from 2010 to 2023. Price data were collected from the Agrarian Research and Training Institute of Sri Lanka. of upcountry vegetables including carrots,

green beans, leeks, tomatoes, and beetroots in the Colombo city region The main data analyzed for the development of the models were the monthly retail prices markets. In the ARIMA modeling approach, lag and the first difference were drawn to utilize the raw data to transform data to stationary, if not the ARIMA models will not be suited with raw data.

The Autoregressive Integrated Moving Average (ARIMA) model is a statistical approach used for analyzing and predicting time series data. It consists of three components: p, d, and q. The parameter p represents the auto-regression, which indicates the lag order. The parameter d represents the degree of differencing, and the parameter q represents the order of the moving average.

ARIMA models are widely used in various fields, such as finance, economics, and forecasting. They utilize past values of a time series to predict future values and can help understand the underlying patterns and trends in the data

The ARIMA model can be extended to the Seasonal Autoregressive Integrated Moving Average (SARIMA) model, denoted as ARIMA (p, d, q) × (P, D, Q)[S]. In SARIMA, the additional parameters P, Q, and D represent the seasonal autoregressive order, seasonal moving average order, and seasonal differencing order, respectively. It is important to thoroughly analyze the time series data before fitting a SARIMA model . Seasonal ARIMA, is an extension of ARIMA that explicitly supports univariate time series data with a seasonal component. It adds three new hyper parameters to specify the auto-regression (AR), differencing (I), and moving average (MA) for the seasonal component of the series, as well as an additional parameter for the period of seasonality.

Then two correlograms of Autocorrelation Function (ACF) and Partial Autocorrelation Function (PACF) were used to manually specify an ARIMA model as it gives a clue to find the p, d, and q values. The ACF plot expresses how far the present value is related to its later values while the PACF plot describes the correlation between the time series variable and its lags.

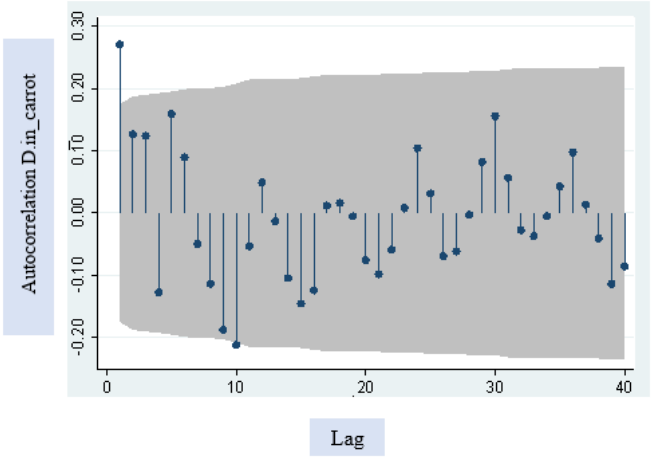
The Ljung and Box "Q" statistics are used to assess whether the autocorrelations of the errors in a time series are significantly different from zero. This test helps determine if there is any remaining autocorrelation in the residuals of a model. Augmented Dickey-Fuller (ADF) test is commonly employed to examine the stationarity property of a time series. It helps determine if a series is stationary or if it requires differencing to achieve stationarity [6]. All the analyses in this study were carried out using the Stata 5.0 package. The Ljung Box test was used to check the accuracy of the proposed model. The likelihood, Akaike information criterion (AIC), and Bayesian Information Criteria (BIC) were used to select the best-fitted model from the proposed models.

III. Results and Discussion

According to the time series plot, there was a slight upward trend, non-constant variance, and a clear seasonal pattern in monthly retail prices of carrots, beans, tomatoes, beetroot, and leeks were observed. As the raw data was non-stationary, transformed them into a stationary time series through one-degree differencing. After completing the appropriate procedures (Fig. 1), a more appropriate mathematical model for estimating the retail price of each commodity was derived.

As mentioned in the below flow chart (Fig. 2), firstly Augmented Dickey-Fuller test was performed and it showed a unit root in the time series which denoted the data set was non-stationary. The first differentiation was taken to make the data stationary. Then plotted Autocorrelation Function (ACF) and Partial Autocorrelation Function (PACF) were employed to identify the order of auto-regression (AR) and moving average (MA).

(A)



(B)

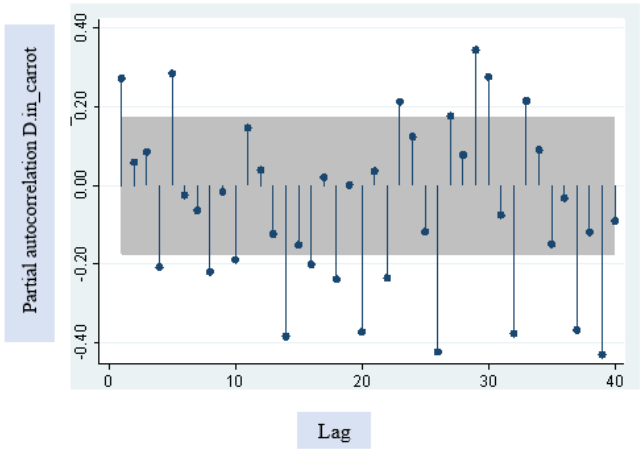


Fig 1. shows (A) the Autocorrelation graph of the carrot (B) the Partial autocorrelation graph of the carrot

The best models were ARIMA (1,1,1) (0,0,1) for carrots, ARIMA (2,1,1) (0,0,1) for beans, ARIMA (2,1,0) (0,0,1) for leeks, (1,1,2) (0,0,1) for tomatoes and ARIMA (1,1,1) (0,0,1) for beetroot.

As mentioned in Tab. 1, the results of the ARIMA model predictions indicated that the Mean Squared Error (MSE), Root Mean Squared Error (RMSE), and Mean Absolute Error (MAE) for the models of five vegetables were all close to zero. Additionally, the Mean Absolute Percentage Error (MAPE) was found to be less than 30%. When comparing the ARIMA models for the prices of the five vegetables, it was observed that the carrot and tomato price models provided the most accurate predictions. The absolute percentage error for this model was within 5%, and it

demonstrated a high level of accuracy in simulating the true values.

In conclusion, a variety of factors interact to affect vegetable pricing along the whole supply chain, and changes in these aspects in the future are uncertain. The price forecast trend line that is closest to the actual value, namely the ARIMA forecast curve, should be chosen as the reference when vegetable producers make production and planting plans as a result, helping producers decide whether to increase, decrease, or keep the output unchanged and lowering the production risk of vegetables with perishable characteristics.

IV. Conclusion

The best SARIMA models were ARIMA (1,1,1) (0,0,1) for carrots, ARIMA (2,1,1) (0,0,1) for beans, ARIMA (2,1,0) (0,0,1) for leeks, (1,1,2) (0,0,1) for tomatoes and ARIMA (1,1,1) (0,0,1) for beetroot.

When vegetable producers are making production and planting plans, it is important for them to consider the price forecast trend line that closely aligns with the actual value. In this case, the ARIMA forecast curve serves as a reliable reference. It is evident that all five main upcountry vegetables experience significant fluctuations throughout the year.

Price forecasts should be communicated among vegetable growers using all media platforms.

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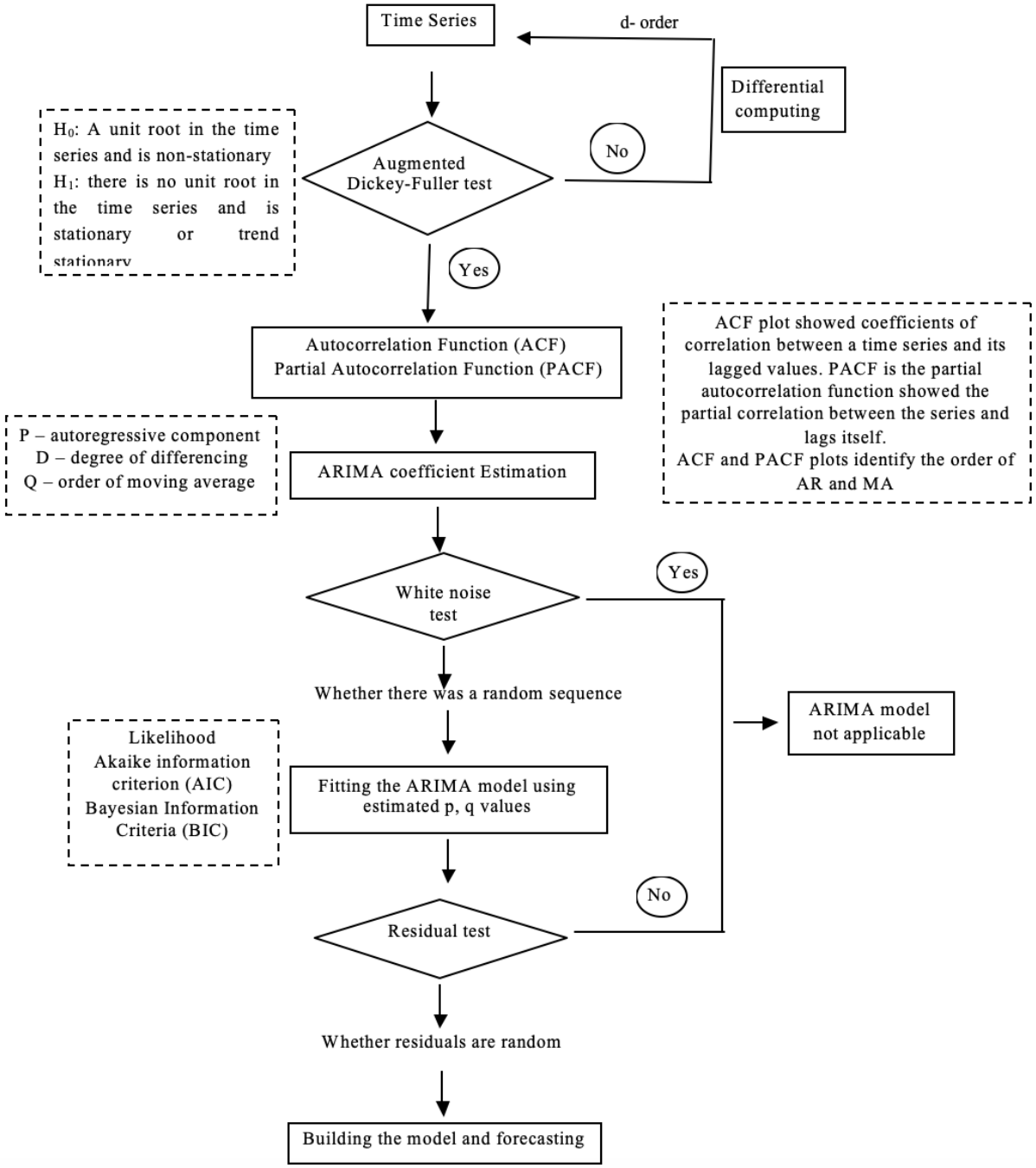

Fig. 2. ARIMA model flowchart for price prediction

TABLE 1. EFFECTIVENESS OF AVERAGE VEGETABLE PRICE FORECASTS (*SOURCE: AUTHORS*)

		MSE	***RMSE***	***MAE***	***MAPE%***
Carrot	ARIMA (1,1,1) (0,0,1)	0.23	0.14	0.12	4.8
Beans	ARIMA (2,1,1) (0,0,1)	0.33	0.58	0.61	29.5
Tomato	ARIMA (1,1,2) (0,0,1)	0.12	0.11	0.14	4.1
Leeks	ARIMA (2,1,0) (0,0,1)	0.27	0.46	0.48	13.2
Beetroot	ARIMA ((1,1,1) (0,0,1)	0.48	0.68	0.71	18.6

∗ Average error values in percentage terms. Values at least 0.15 equate to 15% error was a better fit. Smaller values indicate better fit.

* Squared errors are based on the square of the differences between the fitted values and the observed values. It's similar to a standard deviation value. Smaller values indicate a better fit.

2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

Enhancing Employee Engagement in the Bag Manufacturing Industry: A Deep Dive into the Impact of Operational Technology Application

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***Abstract*—Operational technology applications underscore the importance of enhancing organizational efficiency and effectiveness. The bag manufacturing industry is increasingly embracing new operational technologies. Thus, this review study aims to investigate whether the implementation of technology has contributed to an increase in employee engagement within this industry. The research methodology used in this study involves conducting an Integrative Literature Review. This comprehensive approach includes a systematic examination of various scholarly sources, such as research articles, books, and other published texts, to gather and synthesize relevant information and findings. It is evident that a positive relationship exists between employee engagement and the application of technology. The impact of technology application on employee engagement is unquestionably positive. In the context of the bag manufacturing industry, technology application can be effectively assessed by considering user involvement and training provided for handling specific technologies. On the other hand, employee engagement can be comprehensively evaluated by considering three crucial dimensions: vigor, dedication, and absorption. These elements collectively provide a robust framework for assessing and understanding the level of employee engagement in this industry. The synergy between technology and employee engagement offers valuable insights for improving workplace dynamics and productivity in the bag manufacturing sector.**

Keywords—Technology application, user involvement, training, employee engagement, vigor, dedication, absorption

I. INTRODUCTION

Operational efficiency encompasses the capacity to assess, analyze, and enhance processes within an organization or business [13]. Various industries have long employed technology in their operations. Consequently, firms in both manufacturing and service sectors typically view customer expectations and technological advancements as the primary catalysts for operational changes [1] With the advance and features of block chain technology, new innovation and applications may strengthen platform operations naturally [16]. Accordingly, Fiddle (2023) has identified technology has drastically improved and accelerated the efficiency of business operations and implementing technological aspects could put the business well on its way to becoming more operationally efficient. The artificial intelligence (AI), automation, information technology, robotics, cloud computing, nanotechnology, military technology and control system are the firms that utilize technology systems in following ways in operations management in the world [16].

Further, bags.bg (2013), has explains the Extrusion as known as blown film extrusion and used to convert to foils and sleeves in carious thickness, sizes, colors and other properties. Roll lamination has used a technology with two-component glue to bond materials and far more eco-friendly than many other comparable processes. Sheet lamination has used an automatic machine for hot laminating. Die cutting and ceasing have used hot stamping or embossing and are cut and creased with great precision by means of automatic or semi-automatic, machines. Laser cutting technology hast used to cutting the designs of bags. Those are designing with soft wares as adobe Photoshop, canva, adobe illustrator, marvelous designer and etc. But the pivotal question is how these technologies affect employees – whether they heighten employee enthusiasm and engagement in their work or, conversely, diminish their engagement.

The employee engagement is a human resource concept that describes the level of enthusiasm and dedication a worker feels towards their job [17]. In the world, have to track that employee engagement metrics across thousands of organizations globally using the engagement survey. According to that survey there are 23% employee engagement and 18% actively disengaged globally today world [2]. Around 14% employees are engaged, 62% are disengaged and 23% are actively disengaged to their works in organizations in Sri Lanka. Given the significance of employee engagement and the prevalence of disengagement, it becomes imperative to assess the impact of technology within the bag manufacturing sector on employee engagement. This review study aims to determine whether technology applications have contributed to an increase in employee engagement within the industry.

II. THEORETICAL REVIEW

A. Technology Application

The technology become a key of foundation and development to competitiveness and survival of free market [10]. Have to flexible in order to improvise with technological complexity. Because one of the fundamental purposes if technology is to contribute to economic growth [6]. According to Kraugusteeliana et al. (2023), identified the business are not required to rely solely on the government; rather they should end over to eliminate any technological impediments they may face by maximizing the government. Numerous practical applications in aerospace, automotive, biomedical, energy and other fields and main processes, materials and applications of the current technology and presents future research needs for this technology [17]. In order to measure the extent to which information technology

provides competitive advantages, was operationalized [15]. According to Kraugusteeliana et al. (2023), the companies are ready to replace the role of humans with technology while the human or employee aspect is not ready to use sophisticated technology when working. The benefits of automation and technology integration in production and the emergence of further advanced technologies paved the way for a large leap in the industrial world [13]. According to Kraugusteeliana et al. (2023), the presence of technology has influenced the community and the surrounding environment. Where technology can help in a variety of ways, such as by improving the economy.

B. Employee Engagement

Employee engagement is a critical tool for effective tool management. And also, it enhances the competitiveness and image of an organization. Further that is great impact on growth of and organization and global economy [7]. According to Ajayram and Velmurugan (n.d.), employee engagement is the deviation, passion, of employees and effective leadership skills with support from the top management to the employees. New measurements have been proposed to judge user involvement and system support. With respect to user engagement, four elements have been identified, including the point of engagement, the period of sustained engagement, disengagement and re-engagement [20]. It also supports to in maintaining a higher level of commitment. Employee engagement is the level of employee's commitment and participation towards their organization and its values [2].

People crate and operational use the organization's strategy; and the engagement will be intrinsically linked to the quest for high levels of operational performance or strategic advantage [19]. According to Sun and Bunchapattanasakda (2019), employee engagement is an important issue in management theory and practice. And also, still there are major differences in the concept, theory, influencing factors and outcomes of employee engagement. Engaged employees have a sense of attchement towards the organization and invest themselves in their roles and the organization as a whole [3]. There are some benefits on the employee engagement. According to Turner (2020), promised benefits of employee engagement are higher productivity, more discretionary effort, more rapid innovation and faster time to make.

III. METHODOLOGY

The research methodology employed in this study involves conducting an Integrative Literature Review. This comprehensive approach involves a systematic examination of various scholarly sources, including research articles, books, and other published texts, to gather and synthesize relevant information and findings.

To accomplish the research objectives, this methodology encompasses a thorough critique of the identified literature, where the strengths and weaknesses of each source are evaluated. It also involves the synthesis of these findings, allowing for the creation of a cohesive and comprehensive narrative that brings together the relevant knowledge and insights from the selected sources. This integrative approach aims to provide a well-rounded understanding of the subject matter and contributes to the achievement of the study's research objectives.

IV. FINDINGS

The findings highlight a significant gap in the research landscape concerning the global bags industry. To thrive in the bag manufacturing sector, industry leaders must possess a well-rounded set of professional literacies, comprising knowledge, skills, attitudes, and values. This requirement extends to various roles within the industry, including bag designers, manufacturing technicians, patternmakers, hand-stitches, and production supervisors, all of whom stand to benefit from acquiring these essential professional literacies [12]. A noteworthy development in the bags manufacturing sector is the emergence of luggage tracking as a pivotal innovation. The Internet of Things (IoT) plays a pivotal role in implementing effective tracking systems. IoT technology empowers devices to monitor luggage in real-time, offering location-based information to users [3]. However, it is crucial to note that there is a paucity of research exploring the relationship between technology and employee engagement in the bags manufacturing industry, particularly in the context of Sri Lanka.

Unfortunately, the research landscape does not yield any studies investigating the impact of operational technology applications on employee engagement in the bags manufacturing industry in Sri Lanka. This reveals a significant research gap, especially from the perspective of Sri Lanka. Nevertheless, the available evidence suggests that the adoption of cutting-edge technology has the potential to exert a positive influence on employee engagement within this industry. The bags manufacturing industry has updated anytime with new technology aspects because they bag manufacturing industry use technology for all of their operations during the manufacturing process in the world. Though there some very attractive facts have identified on this technology applications in bags industry in Sri Lanka. That is the laser technology, which is used for their operations for designing their bags in Sri Lankan manufacturing industry. Majority of machines are automated and working with less number of operators.

Further to that, user involvement, which is defined as a series of cognitive processes and behavioral activities that users perform to accomplish different types of search tactics while interacting with information retrieval (IR) systems [20], has been identified as a way of measuring technology application. According to Xie and Matusiak (2015), users need to be intellectually engaged while system assists them by providing different system features. User-centered design is an essential component in any information technology development. User involvement and feedback during the development process ensures that the final products meet user expectations, fulfill the task requirements, and provide a stable and suitable solution to enhance the overall user experience [15]. According to Xie, Joo and Bennett-Kapusniak (2013), have explored various types of user involvement and system support relative to different types of search tactics occurring during interactions with four type of IR systems: web search engines, online public access catalogs (OPAC), online databases and digital libraries. User involvement in system development is becoming more salient due to the fact that this can lead to better designed

products from the perspective of customers [5]. Further, that user involvement is playing a more and more vital role in the system development cycle and meaningful involvement of users in system development coupled with overall user orientation has been identified as being critical to the success of any project [9]. According to Karwowski, Rizzo and Rodrick (2003), user involvement allows for obtaining stuffiest information about the initial system requirements, for assessing if a product meets the end users' requirements and needs, and for gathering data for the next version of the design. Another technology application is training literature which will be discussed in the next paragraph.

Boothby, Dufour and Tang (2010), have identified the combination of technologies and types are commonly undertaken by firms, presumably as part of their strategies to effectively utilize the adopted technologies and to improve their economic performance. The technological advances have helped to position technology based training applications as practical tools for addressing these demands [8]. That simply investing in new technologies is unlikely to provide competitive advantage and that the full benefits of new technologies are only realized when they are used together with new workplace organizations including training [10]. According to Bell and Kozlowski (2007), companies can effectively use technology to deliver training and meet their human capital development needs.

Training is often used to meet the challenges for two reasons. Such as training is less costly and training can change user's attitude towards adopting new technologies and increase the acceptance [10]. Further, Batool et al. (2021), who has identified there is a relationship between training and HR technology. They help the employees develop their skills, knowledge, learning abilities and promote emotional intelligence. Bell and Kozlowski (2007), has been identified as potentially impact on the effectiveness of technology-based training involves characteristics of the technology. And who has founded that the quality of the technology often exhibits a relationship with training effectiveness. Batool et al. (2021), The factors and importance of training for developing the employees and focus that how HR technology and e. practices help the HR consultants to make the training more efficient, and what type of technology use in training and how to improve the training that helps in employees' development.

Subsequently, various methodologies for assessing employee engagement were examined by reviewing a range of articles. As per Schaufeli et al. (2019), employee engagement composed with 3 items are feeling energy (vigor), enthusiasm (dedication), and immersion (absorption). According to Cortés-Denia et al. (2023), work engagement is composed with vigor, which refers to the level of energy, effort and resilience displayed in the workplace. An engaged and proactive person—someone who has not just the willingness, but the physical energy to go the extra mile, or, as it's known in the trade, "discretionary effort." [11]. The vigor at work and work engagement were important variables to explain the authentic leadership-job satisfaction relationship in both private and public organization [11]. According to Lopez-Zafra, Pulido-Martos and Cortés-Denia (2022), have identified the vigor as an affective dimension mediates the effect of positive leadership on engagement and have analysed the relations of both leadership styles to vigor, and affective construct, and engagement at work, a motivation outcome.

Vigor at work has been defined as a positive affective state characterized by experiencing feeling of physical strength, which represent physical capacities of the individual; emotional energy, such as the ability to show and express empathy and companion to other people; and cognitive aliveness, which is described as the flow of thought processes and mental agility [11]. Further, feel the well-being that triggers positive affect, a magnetic force that can propel you and others beyond obstacles. You are willing to draw on that energy to go beyond the normal level of effort [11]. Another dimension is dedication in employee engagement literature which will be discussed in the next paragraph.

Dedication refers to being strongly involved in one's work and experiencing a sense of significance, enthusiasm and challenge. Accordingly, vigor and dedication are considered direct opposites of exhaustion and cynicism, respectively, the two core symptoms in burnout [4]. Work engagement refers to a positive, affective-motivational state of high energy combined with high level dedication and strong focus on work [6]. According to Bakker and Albrecht (2018), have identified their strong dedication to and focus on their work activities. Engaged workers show better in-role task performance. It's the opposite of the cynicism that comes from burnout, which sees any self-initiative as futile and naïve. Burnout can't coexist with the passion and loyalty of dedication [11].

Bakker, Demerouti and Sanz-Vergel (2014), have explored the volunteers had worked with great dedication and enthusiasm for several months prior to the onset of these symptoms. The need to feel effective is critical to self-worth. Dedicated employees feel valued, because they have opportunities to contribute and make a difference [11]. The individuals who burn out from their work deplete and their energetic resources and lose their dedication to work in organization [4]. According to Rustiawan et al. (2023), employee is confronted with challenging job demands, job resources become valuable and foster dedication to the tasks at hand. Further, employees will provide full of dedication if the company pays attention to several factors. Including respecting employee needs, internal training and the development in the company, and the ability to retain employees. Another dimension is absorption in employee engagement literature which will be discussed in the next paragraph.

Refer to the absorption, which is person's state of mind that is more pervasive and persistent [4]. Absorption is characterized by complete concentration and preoccupation with work, where time passes quickly and a person has difficulty separating from work [22]. But further, Jaya and Ariyanto (2021), have identified absorption on performance has a very weak positive significant effect. Your skills meet a challenge in the moment, there's a sense of mastery, a loss of self-consciousness, and a clear focus, not to mention a sense of competence and autonomy, and that satisfies two core psychological needs [11]. According to Jaya and Ariyanto (2021), that absorption has a significant positive effect on employee productivity and job performance.

And also, it feels of a person braking away from the surrounding environment, high concentration and not paying attention to the time that passes. Absorption here signifies the working for an institute with immersed in work, happily performing at workplace and forget everything when they are at work. A high-level absorption will result in better performance, because absorption represents an attitude of concentration and seriousness in work [4].

The literature review found that very little literature reviews has been done on the operational technology application in the global context. The topic of the Effect of Operational Technology Application on Employee Engagement in the Bag Manufacturing Industry in Sri Lanka has not been researched before. The Firstup (2022), indicates the employees have to involve their works, enthusiastic about the organization they work for, have a sense of belonging and be afforded flexibility around schedule and location and easiness doing works. Hence, the employee engagement and the technology application has a relationship is a positive impact of technology application on employee engagement. Technology has given influence to an organization, not only the organization, but the influence extends to employee engagement [23]. As an examined of the study, have to realize there is strong positive relationship with technology and employee engagement for their operations in bags industry.

V. Conclusion

It is evident that there exists a positive relationship between employee engagement and technology application. The impact of technology application on employee engagement is indeed positive. In the context of the bag manufacturing industry, technology application can be effectively gauged through the lenses of User Involvement, and this is closely tied to the training provided for the handling of specific technologies. Employee engagement, on the other hand, can be comprehensively measured by considering three vital dimensions: vigor, dedication, and absorption. These elements collectively provide a robust framework for assessing and understanding the level of engagement among employees in this industry. This interplay between technology and employee engagement offers valuable insights for enhancing workplace dynamics and productivity in the bag manufacturing sector.

VI. Recommendations

Given the absence of any existing studies on this particular topic within the context of Sri Lanka, it is highly recommended that further research be conducted to investigate and understand the impact of technology application on employee engagement in the bag manufacturing industry. This research gap presents a valuable opportunity to delve into unexplored territory and explore the complex dynamics between technology adoption and employee engagement within the Sri Lankan context.

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2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

Case Study on Performance of Post Office– Panadura

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***Abstract*—The postal service organization is among the most important service organizations in any country that providing customers with proper services leads to their satisfaction. As a service-providing organization, considering the customers' needs is an important factor in the success of the postal service. This study aims to analyze the customers' waiting time through computerized simulation and suggest ways to increase organizational efficiency to increase customers' satisfaction. The simulation of this single server queuing system was performed using Rockwell ARENA. Primary data collection was done taking into account customer arrival time, waiting time, and service time. Secondary data were collected through journal articles, books, and other written sources to develop a literature review and conceptual model. The ARENA model for, the existing system was developed using the identified statistical probability distribution. The sample was selected from the customers who were served at each service counter from 8 a.m. to 3.00 p.m. on weekdays. In the existing system, higher waiting times were identified especially at the public allowances counter. The results explain the average waiting time in the public allowances queue to be 48.6 minutes. The number waiting at the counter was 14.8 customers. The existing system needs to be improved to minimize the waiting time of the customer while reducing the cost. The most efficient proposed model was to add an extra resource to the public allowances counter and increase the efficiency of the service providers of the remaining counters to increase the service performance. The study further revealed the possibility of reducing waiting time at the allowances counter to 0.5 minutes by doubling the resources at the counter. Performance was increased by 97% of the proposed model.**

Keywords—ARENA, post office, simulation, single server, waiting time

I. INTRODUCTION

In Sri Lanka, the postal service is a common service that most of the general public use in their daily lives. Mail products, mail services, philatelic products, money transfer services, banking services, insurance services, social and obligatory services, utility payment services, examination services, booking services, and postal facilities are the main functions of postal service. Since the number of services offered by a Post office is high, the number of customers who expect to receive postal services is also high (Soni & Saxena, 2011). In most post offices, there are considerably large queues. Further study of these waiting lines at the post offices revealed that there was a considerably high waiting time. This research was prompted by the fact that previous researchers' solutions to the long queues at post offices counters in Sri Lanka through the ARENA software were minimal, and that prior researchers had not paid attention to solving long and irregular queues in the postal service, which has become a major problem.

The objective of this study is to provide cost-effective solutions to the problems identified in the post offices, such as long queues, long waits, and unnecessary waiting times while enhancing the efficiency of the post office. The significance of this study is to provide theoretical solutions to the long queues and waiting periods that can be seen in post offices in Sri Lanka and increase the performance and efficiency of post offices through practical and cost-effective solutions.

Mainly, there were four service counters available at the post office, namely;

- Local and foreign parcel/stamp counter
- Register post counter
- Public allowances counter
- Money order/ bill payment counter

Counter 01: The first counter is designated for accepting local and foreign parcels and issuing stamps. This counter is very crowded because the above two services are offered at the same time.

Counter 02: The second counter is for registering posts. This counter is normally busy, and especially in the evening, this counter becomes busier. This is due to the government offices that are located nearby bringing their mail to post in the evening.

Counter 03: The third counter is for issuing public allowances such as pensions, elderly allowances, and farmer's pensions. Since these allowances are issued on selected days of each month, this counter is crowded only for a particular period of each month.

Counter 04: The fourth counter is designated for placing money orders and paying bills, including water bills, electricity bills, and phone bills. This counter is crowded most of the time. The customer who wants to place a money order first arrives at the counter and collects the form to fill it out, then fills out the form and enters the queue to place the money order. Customers who want to pay their bills directly enter the queue.

II. Literature Review

The higher the number of services offered the number of customers who require those services get higher. Then the concept of a waiting line or queue occurs. The queuing theory was developed to analyze the telephone traffic density (Soni & Saxena, 2011) and is currently used to study queuing phenomena in (Gross and Harris, 1985) transportation, business industrial service systems, variable reservoirs, (Soni & Saxena, 2011) ATM, bank, petrol pump and retail shops.

Otilia and Jaradat (2010) state that, the waiting line model plays a major role in operational effectiveness. The waiting line is a primary source of customer dissatisfaction and the cost of dissatisfaction is non-negligible (Fink and Gillett, 2006). To enhance the effectiveness, (Otilia and Jaradat., 2011) suggested increasing the average service rate or to add new service channels. Reducing the average service time can perform by redesigning the waiting line or using new technology.

Characteristics of a queue consist of the calling population, arrival pattern, distribution of customer arrival, service pattern, service time distribution, queue discipline, length of the queue, queue behavior, and exit from the queue. The customer's perception of service quality depends on the efficiency of waiting time. To get customer satisfaction, the waiting model should be managed properly and sufficient capacity should be provided. The cost of waiting is different from one person to another and so the study of the waiting model is crucial (Friedman and Friedman, 1997). When waiting is examined as a psychological experience, identified that the people who wait in a single queue feel more predictable and arousal than those waiting in multiple queue lines (Rafaeli, Barron & Haber, 2002). When there are multiple queues, before joining a specific queue, the customer will inspect the queue or join the queue balk. This inspection is associated with a cost (Hassin & Green, 2017).

The aim of developing a waiting line model graphically is to identify the issues and describe the waiting system without implementation. That is important in reducing costs which is related to the waiting line.

Sri Lanka post was established in 1798 with five offices. Currently, there are 4692 post offices around the country with more than 19000 employees. They offer various types of services to the general public and post offices are considered one of the most commonly used formal communication methods in the country. Mainly Sri Lanka postal service offers mail products, mail services, philatelic products, money transfer services, banking services, insurance services, social & obligatory services, utility payment services, examination services, booking services, and postal facilities (Source - Sri Lanka post website).

According to Kendall's classification, a post office queue classifies as a system with an infinite queue with exponentially distribution of arrival and service times and waiting for the discipline of FIFO (first in first out) (Dutkova, Achimsky & Drozdziel, 2020).

Dutkova, Achimskya, and Hostakova (2019) stated that in a queue of a post office, many random variables cannot be captured in the analytical solution of the optimization problem. The simulation model which is closer to the actual model should be used in analyzing the model.

III. Methodology

In this study, computer simulation by ARENA software was chosen as the methodology to determine a solution to the identified problem.

3.1 Data Collection

Primary data collection was done taking into account customer arrival time, waiting time, and service time. 150 data for each service counter were observed in minutes using a stopwatch. Secondary data were collected through journal articles, books, and other written sources to develop a literature review and conceptual model.

3.2 Sampling Procedure and Population

The sample was selected from the customers who were served at each service counter from 8.00 a.m. to 3.00 p.m. on weekdays. The tenth day of the month in which the pension allowances were paid, was selected to collect data because it was discovered that there was a long and irregular queue at the public allowances counter. Data were also collected the next day to avoid bias in data collection.

3.3 Data Analysis

With the observed data, the arrival distribution and the service distribution were analyzed using the Input Analyzer of the ARENA software. Inter-arrival times and service times were entered into the ARENA Input Analyzer and identified statistical probability distributions. Then the identified probability distributions were considered for designing the ARENA model.

3.4 Model Development

The ARENA model for the existing system was developed using the identified statistical probability distributions. A few assumptions were followed up to analyze the model namely;

- Customers are served on a First-In-First-Out (FIFO) basis.
- Continuous service was provided by the server.
- A single customer only gets the service once.
- Customer arrival is independent and infinite.
- The system has an infinite waiting room.

IV. Results and Discussion

The input analyzer of the ARENA was used to obtain the probability distributions of the arrival and service rates. Obtained values are shown in Tab. 1 and Tab. 2.

TABLE I. Arrival Distributions of the Existing System

Counter	Distribution	Expression
Parcel and stamps counter	Weibull	0.999 + WEIB (0.247, 0.278)
Register post counter	Gamma	-0.5 + GAMM (2.17, 1.67)
Public allowances counter	Lognormal	-0.5 + LOGN (4.41, 4.58)
Money-order and bill counter	Lognormal	-0.5 + LOGN (5.16, 6.04)

TABLE II. Service Rate Distribution of the Existing System

Counter	Distribution	Expression
Parcel and stamps counter	Beta	1.5 + 7 BETA (0.585, 3.54)
Register post counter	Lognormal	1.5 + LOGN (1.53, 1.32)
Public allowances counter	Poisson	POIS (4.29)
Money-order and bill counter	Gamma	1.5 + GAMM (1.34, 1.69)

The developed ARENA model for the existing system is shown in Fig. 1. The model was developed using the basic process panels such as create, process and dispose and advanced process panels such as routes and stations.

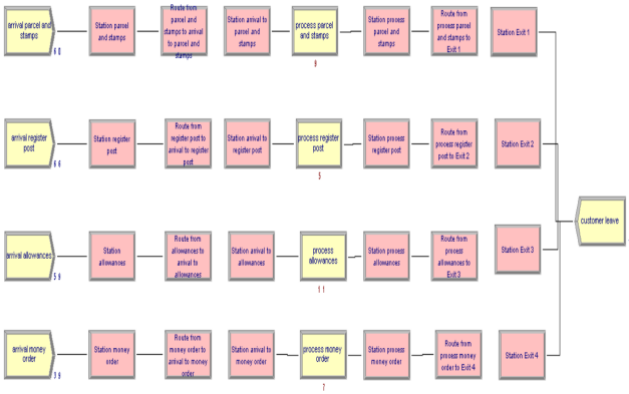

Fig. 1. ARENA simulation model of the existing system

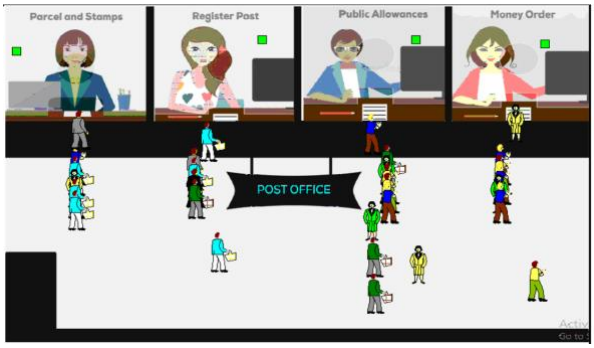

Fig. 2. The animated model of the existing system

4.1 Proposed Model

The existing model shows considerably high waiting times for all the service counters while only the public allowances counter shows a higher waiting number of customers to receive the service. The proposed model aims to minimize the waiting time of the customer while reducing the cost. To identify the most optimal method, 15 proposed models were analyzed. By adding an extra resource to each counter, a theoretically optimal solution can be generated which reduces the waiting time of the customer. But considering the cost of adding extra resources and the cost of operations, the most efficient proposed model is identified as the model which added an extra resource to the public allowance counter. To increase the service performances of the remaining counters, increasing the efficiency of the service providers is suggested.

TABLE III. Output Data of Proposed Models

		Existing model	Proposed model
Number in		408	353
Number out		364	342
Customer served %		89.22	96.884
Waiting time (minutes)	Stamp and parcel	10.6635	8.143
	Register post	6.2968	6.4584
	Allowances	48.5781	0.4735
	Money order	11.7081	8.152
Number waiting	Stamp and parcel	2.3993	0.9772
	Register post	1.8131	1.8406
	Allowances	14.7657	0.1255
	Money order	2.3043	1.7323

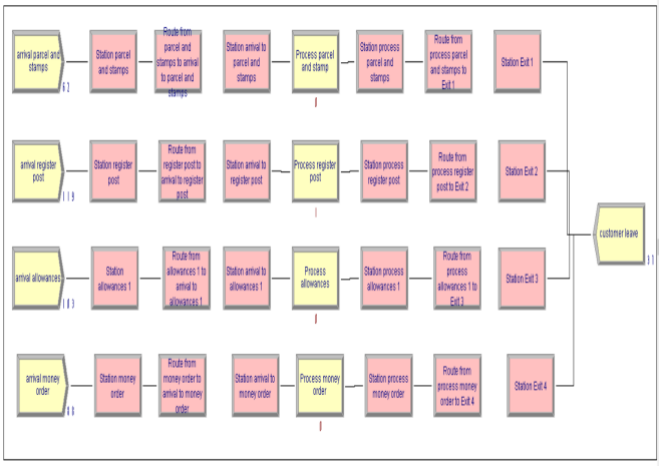

Fig. 3. ARENA simulation model for the proposed system

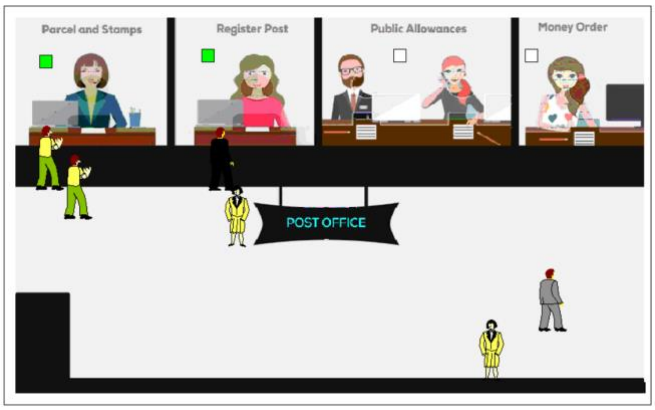

Fig. 4. The animated model for the proposed system

V. Conclusion and Recommendations

This study is aimed at stimulating and analyzing the performance measures of the existing four sections in the post office. By using ARENA, the average waiting time of the customers and the number of customers waiting in the queues were calculated. That analyzed performance was given that a large number of customers are waiting to receive services of the public allowances counter as compared to other counters. Thus, the existing system needs to be improved to minimize the waiting time of the customer while reducing the cost. According to the requirement, 15 models were modified and tested. The results revealed that if an extra resource is added to each counter, reduces the waiting time of the customer. But it was the only theoretically optimal solution. This is because when considering the cost of operations and the addition of additional resources, the most efficient proposed model was to add an extra resource to the public allowance counter and increase the efficiency of the service provider of remaining counters to increase the service performances.

Arena gives the solution only to reduce the long queue and waiting time for customers. But physically, there is another issue. The public allowances counter had an irregular queue. Because that counter provides several services, not just one. Therefore, that place was very crowded as the elderly people came to get all those services and someone else came with them to help them. Though there was allocated a person outside the counter to manage the customers, that person wasn't efficient. As a solution to that problem, it may be suggested to put chairs in place and rearrange the space, as there is ample space in the place. As another solution, it can be suggested to allocate time for each service separately.

Most of the waiting times of each of these counters occur due to the time spent serving the customer. Especially at the public allowances counter, the waiting time is considered very high. Further research can be conducted to identify the reasons for these waiting and implement proper solutions. Furthermore, the layout of the system also affects the service rate because multiple services are offered by the same counter. Future studies can conduct to identify an optimal layout for the post office.

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2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

Developing a Fertilizer Recommendation for Gurmar (Gymnema sylvestre) in the Wet Zone of Sri Lanka

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***Abstract*—Gurmar *(Gymnema sylvestre)* is a rare medicinal plant native to Asia, Africa, and Australia with valuable properties in Ayurveda medicine. This vine helps treat diabetes in patients. As this plant is rare and valuable, it requires development as plantations to increase production and meet the demand. However, there is no proper fertilizer recommendation for this plant. As such, this study aimed to identify optimal fertilizers for high Gurmar plant yield. For this, Urea, TSP (Triple Super Phosphate), and MOP (Muriate Of Potash) were used as a mixture and tested from different rates (Control, +50% controls' weight, -50% controls' weight) with a basal dressing and two top dressings, mainly aiming the vegetative growth of the plants. The number of leaves and plant height were evaluated for 13 Weeks After Planting (WAP). Results showed a significantly higher number of leaves and plant heights in all basal and top dressings with +50% controls' weight. This finding can be used in further research and effectively utilized in the maintenance of large-scale *G. sylvestre* plantations in the wet zone of Sri Lanka.**

Keywords—Gymnema sylvestre, vegetative growth, basal dressing, top dressing, chemical fertilizers

I. INTRODUCTION

The Gurmar plant (*Gymnema sylvestre*) is an Ayurvedic medicinal plant with valuable medicinal properties. It can also be classified as a perennial woody vine. This Gurmar plant belongs to the "Asclepiadacea" family [1]. Not only the leaves but other parts of this plant such as bark, roots, and flowers have medicinal properties. Native to Asia, Africa, and Australia, this vine has been recognized for its potential to treat diabetes in humans. That is, this plant has a strong ability to suppress the taste sensation of sweet substances for several hours. Other than that, *G. sylvestre* has antimicrobial, hypolipidemic, and anti-arthritic activities. This plant is also known as 'Gudmar' because of its rare ability to destroy the sweet taste. The main reason for the plants' anti-diabetic properties can be attributed to the fact that the leaves contain a mixture of tri-terpenes and saponins (Gymnemic acids, Gymmagenin, and Gurmarin) [2]. Recent studies have confirmed that Gymnemic acid is useful for treating diabetes and controlling blood sugar. It also contains cholesterol-lowering, blood-sugar-lowering, anti-cancer and antioxidant properties. Currently, there is an ongoing demand for this plant species due to its medicinal properties. So, to meet the increasing demand and to start the cultivation of the *G. sylvestre* plant on a large scale, it is essential to increase the

growth rate of the *G. sylvestre* plant and to obtain a quantitative and qualitative plant yield. A study conducted in India showed that applying 4000 kg FYM (Farm Yard Manure)/ha is promising for the growth and yield of this plant on a large scale [3]. Therefore, this experiment aimed at developing a proper fertilizer recommendation to improve the growth rate of this plant which can be effectively used in the wet zone of Sri Lanka.

II. METHODOLOGY

This experiment was conducted as open field cultivation from February 2023 to May 2023 at SLTC Research University (6.8557° N, 80.0926° E, 27 m above mean sea level, located in the Low Country Wet zone (WL1a)) Ingiriya Road, Padukka, Sri Lanka. This area has red-yellow podzolic soil. The three-week-old plants were purchased from a certified, local nursery. The plants were established in the field with a spacing of 1 m × 0.75 m. The depth of a planting hole was 0.3 m. Before the application of chemical fertilizers, each hole was filled with 100 g of compost. Also, chemical fertilizers that provide three main nutrients to the plants, (N (Nitrogen), P (Phosphorous), and Potassium (K)) were used which are Urea (46% N), TSP (44% P_2O_5) and MOP (60% K_2O). In this experiment, three treatments were used depending on the application rates (Table I). Treatment 1 (T1) was considered as the control rate and treatment 2 (T2) and 3 (T3) were decided as +50% and -50% from the weight of fertilizers applied in the control rate respectively. The basal dressing was applied to planting holes before planting the plants. After 4 and 8 WAP (Weeks After Planting), top dressings one and two were applied respectively. The first readings of *G. sylvestre* plants were taken 3 WAP and continued up to 13 weeks. The parameters obtained were number of leaves and plant height (cm). The experiment was laid out in Randomized Complete Block Design (RCBD) with ten replications per treatment. Data were analyzed using the ANOVA test and the mean separation was done using Tukey's test. Minitab 19 was used as the statistical software.

III. RESULTS

A. Basal Dressing

The effect of basal dressing was identified in weeks of 3, 4, and 5 of WAP. There, significantly the highest number of leaves were observed with the application rate of +50% controls' weight treatment (T2) during 3 (68.00 ± 5.22), 4 (86.10 ± 6.17), and 5 (106.4 ± 8.35) WAP. A similar trend could be observed with the plant heights, where the same treatment resulted in a mean height of 43.90 ± 3.25 cm, 59.60 ± 2.42 cm, and 72.00 ± 2.89 cm during 3, 4, and 5 WAP respectively (Table II).

B. Top Dressing 01

The effect of top dressing 01 was evaluated with the results of 6, 7, 8, and 9 WAP. Same as the basal dressing best results were given with application rate of +50% controls' weight treatment (T2). A continuous increment of the leaf number and plant heights were observed with that and importantly, the results were significantly different from the other two treatments. In contrast, 7 (23.00 ± 3.90) and 9 (41.00 ± 5.70) WAP the lowest number of leaves were given with the control rate (Tab. 3).

C. Top dressing 02

The top-dressing effect for the second time was studied during the 10, 11, 12, and 13 WAP of the Gurmar plants. According to the results, it can be shown that +50% controls' weight treatment (T2) could give significantly the highest number of leaves and the highest plant height even during the latter weeks of the experiment. However, importantly when it comes to the final weeks it could be observed that significantly the lowest number of leaves had been given with the control rate (Tab. 4)

TABLE 1. THE RATE OF FERTILIZER APPLICATION IN BASAL DRESSING, TOP DRESSING 1, AND TOP DRESSING 2

	Basal Dressing (g/plant)			**Top Dressing 1 (g/plant)**			**Top Dressing 2 (g/plant)**		
Fertilizer	***T_1 (Control)***	***T_2 (T_1+$T_1$50%)***	***T_3 (T_1-$T_1$50%)***	***T_1 (Control)***	***T_2 (T_1+$T_1$50%)***	***T_3 (T_1-$T_1$50%)***	***T_1 (Control)***	***T_2 (T_1+$T_1$50%)***	***T_3 (T_1-$T_1$50%)***
Urea	30	45	15	30	45	15	30	45	15
TSP	60	90	30	-	-	-	60	90	30
MOP	25	37.5	12.5	-	-	-	-	-	-

TABLE II. EFFECT OF BASAL DRESSING ON THE NUMBER OF LEAVES AND PLANT HEIGHT

	Number of Leaves			**Plant Height (cm)**		
Treatment	***3 WAP***	***4 WAP***	***5 WAP***	***3 WAP***	***4 WAP***	***5 WAP***
T1 (Control)	10.143 ± 0.857 [b]	11.71 ± 1.17 [b]	13.57 ± 1.39 [b]	12.71 ± 1.11 [c]	19.43 ± 1.99 [b]	25.29 ± 3.44 [b]
T2 (+50%)	68.00 ± 5.22 [a]	86.10 ± 6.17 [a]	106.4 ± 8.35 [a]	43.90 ± 3.25 [a]	59.60 ± 2.42 [a]	72.00 ± 2.89 [a]
T3 (-50%)	22.78 ± 2.27 [b]	27.00 ± 2.79 [b]	32.11 ± 3.64 [b]	25.33 ± 3.37 [b]	28.89 ± 3.86 [b]	32.67 ± 4.58 [b]

Values in each column represent the means of 10 replicates ± SE (Standard Error). The mean followed by the same letter within each column is not significantly different at $p<0.05$.

TABLE III. EFFECT OF TOP DRESSING 01 ON THE NUMBER OF LEAVES AND PLANT HEIGHT

	Number of Leaves				Plant Height (cm)			
Treatment	***6 WAP***	***7 WAP***	***8 WAP***	***9 WAP***	***6 WAP***	***7 WAP***	***8 WAP***	***9 WAP***
T1 (Control)	14.00 ± 1.62 [b]	23.00 ± 3.90 [c]	32.43 ± 4.54 [b]	41.00 ± 5.70 [c]	28.29 ± 4.30 [b]	33.57 ± 4.34 [b]	40.14 ± 4.20 [b]	52.14 ± 5.48 [b]
T2 (+50%)	121.70 ± 9.66 [a]	141.5 ± 10.10 [a]	157.30 ± 12.30 [a]	174.7 ± 13.20 [a]	81.40 ± 4.29 [a]	99.60 ± 5.50 [a]	118.50 ± 6.70 [a]	138.10 ± 7.86 [a]
T3 (-50%)	39.78 ± 5.03 [b]	51.56 ± 4.54 [b]	64.67 ± 6.06 [b]	80.22 ± 8.27 [b]	35.22 ± 5.14 [b]	47.00 ± 5.66 [b]	57.56 ± 5.66 [b]	66.89 ± 6.54 [b]

Values in each column represent the means of 10 replicates ± SE (Standard Error). The mean followed by the same letter within each column is not significantly different at $p<0.05$.

TABLE IV. EFFECT OF TOP DRESSING 02 ON THE NUMBER OF LEAVES AND PLANT HEIGHT

	Number of Leaves				Plant Height (cm)			
Treatment	***10 WAP***	***11 WAP***	***12 WAP***	***13 WAP***	***10 WAP***	***11 WAP***	***12 WAP***	***13 WAP***
T1 (Control)	50.00 ± 8.36 [c]	60.43 ± 9.29 [c]	70.70 ± 11.80 [c]	83.70 ± 13.10 [c]	59.86 ± 6.42 [b]	73.00 ± 9.64 [b]	82.10 ± 12.40 [b]	90.10 ± 15.00 [b]
T2 (+50%)	185.10 ± 13.10 [a]	196.50 ± 13.30 [a]	212.50 ± 14.90 [a]	226.50 ± 15.90 [a]	155.70 ± 10.20 [a]	171.90 ± 10.70 [a]	190.40 ± 12.50 [a]	210.20 ± 13.40 [a]
T3 (-50%)	99.30 ± 11.00 [b]	114.90 ± 12.40 [b]	130.70 ± 15.80 [b]	145.00 ± 18.20 [b]	75.67 ± 6.98 [b]	87.78 ± 8.79 [b]	102.33 ± 9.53 [b]	111.89 ± 9.56 [b]

Values in each column represent the means of 10 replicates ± SE (Standard Error). The mean followed by the same letter within each column is not significantly different at $p<0.05$.

IV. DISCUSSION

Increased fertilizer use can result in modest but important and rapid gains in yields. In other words, to get a sustained yield, 'necessary' and 'sufficient' nutrients should be available to the plants. On the other hand, most soils require the application of both organic and inorganic fertilizers to reach adequate nutrition levels [4] and the quality of plants may suffer if chemical fertilizers or organic manure are used alone as amendments. Moreover, regardless of the agroecological zones, applying organic manure to all crop groups has been advised to increase crop yield in Sri Lanka [5]. Therefore, in this experiment, all the fertilizer application rates tested were priory provided with compost to ensure the sustainability of the cultivation. Depending on the goal of increasing productivity, different nutrients are required for different levels of crop growth [4]. As the primary aim of cultivating *Gymnema* plants was to harvest their leaves, this study aimed to improve the vegetative part of the crop. Because of that when preparing this recommendation, priority was given to improve the leaf production and height of the plants. This recommendation was created by combining and modifying several crop fertilizer recommendations; such as *Vitis vinifera* (grapes), *Passiflora edulis* (passion fruits), *Trichosanthes cucumerina* (snake gourds), and *Alternanthera sessilis* (Mukunuwenna) available specifically for the wet zone region. Sri Lanka currently advises applying N, P, and K primarily to all crops out of the 17 essential nutrients needed for plant growth [5].

N is a crucial building block of organic molecules, and a lack of it can delay phenological development, reduce crop growth, and lower yield. P is essential for root system development, and water-soluble P fertilizers like TSP can provide rapid availability of nutrients. K is the most prevalent inorganic cation, essential for healthy plant growth and activating enzymes involved in protein synthesis, sugar transport, N and Carbon (C) metabolism, and photosynthesis. K also contributes to yield and quality improvement.

It is advisable to apply N fertilizers multiple times during growth to improve efficiency, which is known as the split application of fertilizers [6]. When N is applied in two split doses than in a full basal application yield can be improved. Therefore, in this experiment, urea was applied as two more top dressings other than the basal dressing (Table I). When looking into the results since all three treatments have given continuous increments of the plants' vegetative growth it can be shown that the split application of urea has a positive impact on the growth of Gurmar plants (Table II).

From the date of transplanting up to the top dressing 1 the required N, P, and K nutrients come mainly from the basal dressing and the rapidly decomposable soil organic fraction. When a lot of base fertilizer is applied, both the N from the base fertilizer and the N from the soil are more readily absorbed, which speeds up plant growth [7]. The same scenario may have occurred with P and K where the +50% fertilizer application rate (T2) resulted in the highest yield within the respective period (Tab. 2).

According to reference [8] on potato plants, it was revealed that while the increase in P and K fertilizers had no significant effect on plant height, the addition of N fertilizers did have an impact. They have further concluded that this is due to the plant experiencing robust growth as a result of a fairly large N application dose. Current results of higher plant height and number of leaves may have been created with the applied urea. By increasing the N content up to 45 g/plant (T2) while providing the highest amount of P and K fertilizers in three application times, it is possible to achieve relatively higher growth without any signs of nutrient toxicity in plants. It has been proven that applying an excessive amount of chemical fertilizers will not increase crop output [5]. This means the +50% application rate of fertilizer for Gurmar plants cultivated in the wet zone of Sri Lanka does not create any toxic conditions for the plants. However, further investigation is necessary to determine if the current proposed application rate can be increased without causing toxic effects on plants while remaining economically viable and chemical composition. Meantime looking for more organic amendments to substitute the nutrient requirement that can be provided solely by chemical fertilizers is highly recommended to maintain *Gymnema* plantations sustainably. It is recommended to explore future research directions by conducting field trials in representative sites in the Wet Zone of Sri Lanka where *G. sylvestre* is commonly cultivated. In this regard, it is important to consider variations in soil types, climate, and other environmental factors.

Also, it is crucial to conduct a thorough soil analysis to determine the nutrient levels, pH, and other properties of the soil in the cultivation area. It is highly recommended to perform additional trials to validate the developed fertilizer recommendations to ensure that they can be used in different seasons and locations within the Wet Zone.

V. CONCLUSION

As *Gymnema sylvestre* gains popularity for its ability to treat diabetes in humans, the demand for its vegetative parts is also increasing. To meet the demand through qualitatively and quantitively improved yield, maintaining *Gymnema* plants in large-scale plantations is mandatory. For that plants should be provided with a balanced N, P, and K fertilizer mixture, and the current experiment was conducted with that aim. Results showed that when *Gymnema* plants were cultivated in the wet zone of Sri Lanka, providing one plant with 45, 90, 37.5 g N, P, K respectively as a basal dressing, 45 g/ plant N in top dressing 1 and 45, 90 g/ plant N and P respectively as top dressing 2 gave the highest yield when applied with compost 100 g/plant. Further investigation is needed to determine if increasing the proposed application rate would be safe for plants and economically feasible. Meantime experiments should be conducted to study the relationship between increment of fertilizer dose with the chemical constituents of the plants.

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2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

Postharvest Losses of Cabbage Along the Market Chain: A Case Study from Sri Lanka

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***Abstract*—Postharvest losses in fresh fruit and vegetables are higher, especially in developing tropical countries such as Sri Lanka. The production of perishables annually faces significant losses along the supply chain, from the farm gate to the retailer market. This study established the extent of postharvest losses in the cabbage market chain in Sri Lanka's wet zone. Random samples were collected from the total harvest of a selected farmers' field in Nuwara-Eliya district and tracked at various market points. There the postharvest practices were observed, and yield weight and loss were calculated. Results showed that from the farm gate to the retailer market the weight loss that occurred from cabbages was 22.44%. The majority of the total loss, accounting for 58.05%, resulted from the cleaning process carried out at the retail market. Upon further investigation, it was revealed that losses were also caused by improper packaging, poor transportation facilities, and handling. To minimize crop losses, proper pre-harvest practices should be followed. Most importantly, post-harvest practices such as maintaining lower storage temperatures, use of appropriate packing materials, and implementing a safe transportation system can help mitigate these issues.**

***Keywords*—Postharvest losses, perishables, tropical countries**

I. INTRODUCTION

Cabbage (*Brassica oleraceae* L.) is a vegetable belonging to the Brassicaceae family, widely grown in Sri Lanka. In upcountry regions with cool climates, cabbage can be effectively grown while varieties that can withstand heat can be grown in dry areas. Usually grown varieties within the country include Hercules, Exotic, AS Cross, XY Cross, Green Hot, and Grand Moist. In 2022 total cabbage production of the country was 116,662.2 t from a cultivated land extent of 4,546.5 ha. A higher production has been recorded mainly from districts such as Nuwara Eliya, Badulla, Kandy, Matale, and Puttalam. Although cabbage production varies, its consumption is fairly distributed within the country because of the higher demand it gets throughout the year.

Leafy vegetables such as cabbage are typically harvested before reaching full maturity when their metabolism is at its peak. This makes them particularly vulnerable to quick spoiling and deterioration due to both physical and microbiological factors, along with their high moisture content which is around 90% [1]. Due to this reason, quantitative and qualitative losses can be incurred from the farmer fields up to the consumer level along the market chain of cabbage. These losses may be caused by one or more reasons such as high harvesting temperatures, rigorous handling of fresh crops after harvest, inadequate pest control management, improper transportation, and less available nutrients during the cultivation period. This study aimed to evaluate the causes of cabbage postharvest losses in Sri Lanka's Wet Zone region and identify feasible reduction measures.

II. METHODOLOGY

A cabbage farmer's field was chosen in Nuwara-Eliya district, Sri Lanka, where a higher cabbage production can be seen throughout the year. There the cabbage variety – "Hekeels" has been cultivated in red-yellow Podzolic soil. Random samples (mesh bags filled with 30-40 cabbage heads) were selected from the total harvest and tracked at each point of the market chain, including the field, wholesale market, and retail market, to collect data (Fig. 1). Information on postharvest practices such as harvesting, handling, packing, transporting, and sorting was observed visually and obtained through verbal communication with stakeholders. The weight of the yield was measured as the weight per bag at each location in the market chain, and the loss at each location was calculated. The statistical analysis was carried out using ANOVA, and mean separation was performed using Tukey's test in Minitab 19.

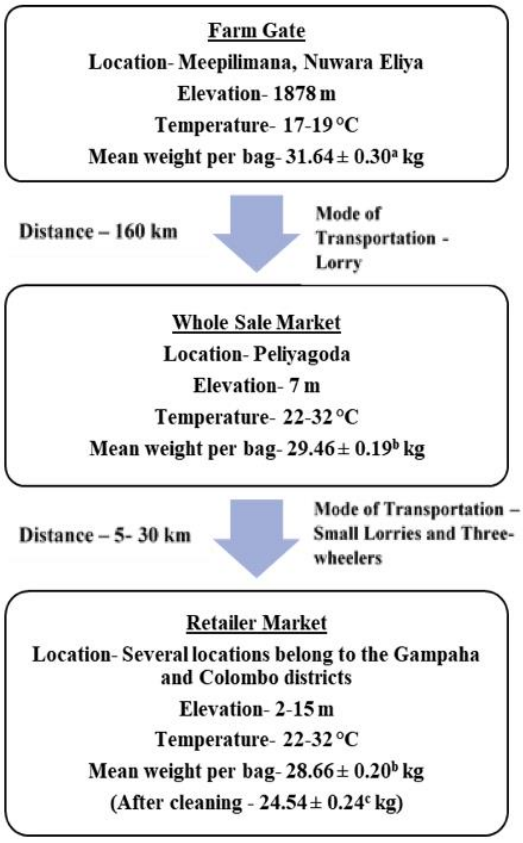

Fig. 1. Each stage's location details, distances, and cabbage weight per bag (mean ± SE of 14 replicates) along the market chain.

III. RESULTS AND DISCUSSION

To identify potential causes and enhance the most effective postharvest techniques, it is critical to understand where losses occur in the food supply chain [2]. According to the current experiment, it can be observed that the weight of cabbages per bag was gradually and significantly reduced along the market chain (Fig. 1.). The percentage loss of cabbages from the farmer field to the retailer market was 22.44%. Several factors may have caused this observation.

The highest percentage of cabbage loss occurred during cleaning at the retailer market (Fig. 2). Before being sold, cabbage heads go through pruning of any damaged and senescent exterior leaves during the postharvest period. This improves the external appearance of the commodity resulting in a high market demand with a high price (Fig. 3C) Although required, trimming cabbages for aesthetic presentation causes the product's overall weight to decrease, which is not what is desired. However, trimming the cabbage leaves during postharvest storage is unavoidable [1]. Therefore, to minimize the losses at this level damages that happen due to transportation, poor handling, improper packaging and insect damage along with microbial spoilages have to be reduced which can appear in the earlier stages of the market chain.

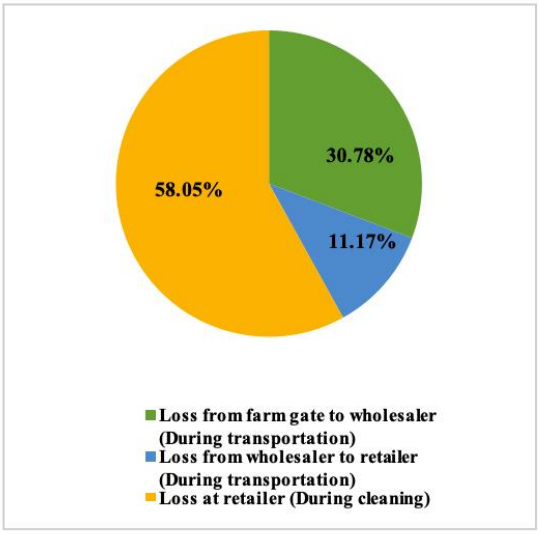

Fig. 2. Percentage weight loss of cabbage at all stages of the postharvest chain (From farmgate to retailer).

Fig. 3. A poly sack bag filled with cabbages in the field (A), A lorry loaded with cabbage-filled poly sack bags to be transported from the field to the wholesale market (B), Cabbage- filled bags heaped at the whole sale market (C), Cleaned cabbages for sale at retail shop (D).

During transportation from farm to wholesaler, proportionately a higher loss occurred as shown in Fig. 2. Several differences can be highlighted in these two locations such as the distance, temperature, and elevation (Fig. 1). Longer distances coupled with poor transportation facilities may have resulted in this particular loss. In most cases, wholesalers prefer to ship the maximum quantity possible to minimize the shipping costs per unit [4]. On the other hand, poor roads, a lack of suitable transportation, and ineffective logistics management make it difficult for underdeveloped nations to effectively preserve perishable crops. Additionally, in these nations, untrained, uneducated employees who typically handle goods carelessly do loading and unloading activities. Agricultural products are mechanically damaged as a result [2]. The types of packaging that traders employ is not designed to account for potential harm caused by erratic road conditions, high ambient temperatures, and humid conditions that occur during the lengthy duration of transportation; in this case, it is 160 km from the farm to the wholesaler market. All of these factors hasten the decline in quality. As time in the vehicle increases, the degree of damage also increases including vibration injury during transportation (roller bruising), impact injury, puncturing injury, and subsequent water loss and microbial entrance. Thus, when produce reaches distribution points, it is frequently bruised, infected with post-harvest diseases, and of subpar quality [3,4]. Poorly made packaging materials are unable to fully safeguard fresh goods against harm and may even enhance their deterioration. During the current study, it could be observed that the farmers and other stakeholders preferred to use poly sack bags which were very harmful to the cabbages. This inappropriate packing material also can be emphasized as one of the major causes of these losses (Fig. 3A). Unfortunately, because they are inexpensive, low-quality packaging materials are frequently used in many regions of the world. Particularly, the usage of subpar packaging containers is more widespread in emerging and underdeveloped nations [2].

In order to ensure the efficient functioning of the cabbage market chain within the country, it is essential to conduct a thorough analysis to identify any existing deficiencies and take action to overcome them.

Usually, vegetable supply chains experience losses at the stages of harvest, handling, storage, processing, distribution, and consumption. If these conditions are not appropriately regulated, large-scale postharvest losses will result. While the changes that happen to fresh produce cannot be halted, they can be minimized with moderate care, including low storage temperatures, relative humidity management, appropriate packing, safe transportation, etc. [2]. In the case of cabbages, the losses that occur in the market chain in Sri Lanka could be observed as discussed above. To minimize the loss due to the excessive trimming at the field level proper pre-harvesting practices should be implemented during the cultivation. Especially, proper attention should be given to nutrient management and insect pest

management. Also, harvesting at the correct maturity level can improve the quality of the final product.

Since Sri Lanka is a humid tropical country with a relatively higher environmental temperature, perishables after harvest tend to decline their quality and quantity rapidly. To avoid that management of the cold chain is really important with proper temperature and relative humidity controls. However, there are currently no services offered for suitably large-scale temperature and humidity-controlled storage facilities within the country [4], therefore government intervention in this matter is suggested.

It is crucial to develop packaging materials that can withstand any potential impacts or mishandling that may occur during the shipping process. Since the stakeholders involved in this process were often economically unstable, they tended to use these sacks. Although the government recommended using plastic crates for transporting perishables, stakeholders did not adopt them due to their high cost and difficult handling. Therefore, to produce a cost-effective and user-friendly packaging system for cabbages, further research and involvement in new technological aspects is necessary. However, reference [5] has shown that using CFB boxes for cabbage transportation was relatively preferable when wrapped in perforated LDPE films [5]. With that, it can be recommended to explore innovative practices implemented by other countries.

Proper government intervention through policies and regulations is necessary to overcome losses, particularly in rural areas. This includes improving infrastructure such as roads, electricity, markets, and communications [3]. Further, advanced knowledge should be disseminated throughout the market chain, highlighting the benefits of its use. To ensure uninterrupted service and the effective transfer of new data, advanced technologies like e-marketing and mobile decision support systems, which include crop forecasting, price forecasting, land use, allocation of resources, and assistance in marketing, should be used and widely adopted by all stakeholders in supply chains.

IV. CONCLUSION

As a developing country located in the tropical region of the world, Sri Lanka faces the challenge of minimizing the quantitative and qualitative losses of perishable fruits and vegetables during their postharvest life. The current study has shown that the postharvest weight loss of cabbage from the farm gate to the retailer market was 22.44%. This loss was mainly due to excessive trimming and cleaning at the retail market, along with poor transportation and packaging facilities. While it may not be possible to completely eliminate these losses, they can be minimized by facilitating proper transportation modes, maintaining a cold chain along the market chain, and using cost-effective and user-friendly packing materials. For this purpose, further research in the relevant subject area and government intervention are highly recommended.

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Enhancing Yield of Tomato (*Lycopersicon esculentum* Mill.) in Sri Lanka Through Organic Fertilizer Solutions

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Abstract—**Limited access to chemical fertilizers has led to yield challenges in the cultivation of tomatoes in Sri Lanka, adversely impacting the livelihoods of growers. This experiment was conducted to assess the efficacy of organic fertilizer solutions compared to conventional fertilization methods. The tested fertilizers included chemical fertilizers for nitrogen (N), phosphorus (P), and potassium (K), organic fertilizer solutions, organic fertilizer solutions combined with Albert's solution, and Albert's solution used independently. Two distinct organic fertilizer solutions were formulated and applied during different growth stages of the tomato plant, namely the vegetative and reproductive phases. The first solution consisted of cow dung, *Glyricidia* leaves, and dried banana leaves, and it was administered throughout the vegetative phase. The second solution, designed for the reproductive stage, comprised cow dung, *Glyricidia* leaves, eggshells, and banana peels. Various parameters were measured, including the number of leaves at 12 Weeks After Planting (WAP) (10.27±0.45), root length (35.53±3.22 cm), and fresh fruit weights (41.00 ±2.31 g), which exhibited superior results in comparison to the other treatments. While the total fruit count per plant remained below average in all treatments, the organic fertilizer solutions demonstrated better overall performance, hinting at their potential as commercially available fertilizers. Nonetheless, further investigations are essential to evaluate their ability to enhance tomato fruits' nutritional and flavor attributes.**

Keywords—Sustainable agriculture, yield, organic, improvement, Lycopersicon esculentum mill

I. INTRODUCTION

Tomatoes (*Lycopersicon esculentum* Mill.) are a popular crop grown in both tropical and temperate regions around the world. It belongs to the family Solanaceae and can be recognized as a perennial or semi-perennial. It can be grown in all agroclimatic zones except the Upcountry Wet Zone in Sri Lanka. Currently, tomatoes have a higher demand because the fruits are used in daily life for fresh fruit consumption, and high-value-added vegetable ingredients like tomato sauce, soup, powders, jam, pickles, curries, and salads. Tomatoes are a common crop with numerous health benefits, including anti-cancer properties due to their vitamin C, fiber, and phenolic components [1]. They also positively impact diabetes, immune responses, exercise recovery, and fertility, making them a valuable addition to overall health. However, within the country, there are several issues concerning tomato cultivation, and there are some barriers to keeping up supply related to the demand. One key issue highlighted within this experiment was the poor accessibility to chemical fertilizers. Many farmers use chemical fertilizers to nourish their plants, but this practice raises both economic and environmental concerns. To overcome those problems, shifting to organic fertilizers can be a better solution.

It is considered that organic fertilizers contribute to the higher growth and yield of crops as they contain major nutrients, micronutrients, growth-promoting factors, and beneficial microorganisms that are involved in decomposition. More importantly, organic fertilizers help to reduce the hazards of using excessive amounts of chemical fertilizers. Organic fertilizers take a due season to produce a higher yield relative to chemical fertilizers and this fertilizer application method is more environmentally friendly and economically viable compared to chemical fertilizers [2, 3].

This study was conducted under a circumstance, where the accessibility to chemical fertilizers was insufficient for the usage and due to its expensiveness in the markets in Sri Lanka. Locally available inputs were used to prepare the organic fertilizer and its effects were compared with the current nutrient-supplying practices among farmers.

II. METHODOLOGY

The research was carried out at SLTC Research University, Ingiriya Road, Padukka, Sri Lanka (6.8557° N, 80.0926° E) in a separated open area as a pot cultivation. The experiment was carried out from November 2022 to February 2023. The study was conducted by using two-week-old tomato seedlings (Variety- Thilina) and they were transferred into poly bags in the size of 40 x 40 cm filled with sand and coir dust (1:1). One pot was planted with two seedlings. The experiment was carried out in a Complete Randomized Design (CRD) at a spacing of 50 x 50 cm with five replications per treatment.

In the experiment, two main organic fertilizer solutions were prepared. The first solution was prepared with Cow dung (5 kg), *Gliricidia* leaves (3 kg), and Dried banana leaves (1 kg). These ingredients were chopped well and then mixed with water (40 L) in a large barrel. Then the barrel was closed and allowed to ferment for four weeks before use. In weekly intervals, the solution was agitated to provide aeration. This solution was applied to the tomato plants aiming their vegetative growth until the seventh week of transplanting. The second solution was prepared using Cow dung (7 kg), *Gliricidia* leaves (5 kg), Banana peels (1 kg), and Eggshells (500 g) mixed with water (40 L). The same after-practices were done as the first solution here as well. After the seventh week of transplanting this solution was added to the plants which were previously treated with the solution one. The frequency and the application rates of the treatments are mentioned in Tab. 1. Most importantly, the fruits from plants treated only with chemical fertilizers started to show Blossom End Rot (BER). To avoid that only those replicates were treated with dolomite (40 g/ plant). The fruits affected were not considered for further measurements.

Growth parameters were measured as the Number of leaves per plant and Plant height (cm) at 12 WAP. At the end of the total life span of the plants, they were uprooted, and the root length (cm) was measured. Yield parameters were measured using fresh fruit weight (g), fruit length (cm), and fruit width (cm) of the fruits harvested at the breaker stage. Data were

analyzed using the ANOVA test and the mean separation was done by using Tukey's method. Minitab 19 was used as the statistical software.

III. RESULTS

a. Growth Parameters

According to the current experiment, there was a significant difference among the fertilizer types for the number of leaves 12 WAP. Plants treated with chemical fertilizers had the lowest number of leaves (6.93±0.28) while the other three treatments gave higher results (Tab. 2). From those three treatments, higher results were given with the organic fertilizer mixture (10.27±0.45). However, there were no significant differences among fertilizer types for the plant heights of tomatoes. When it comes to the root length of the plants comparatively a higher root length was given by the plants treated with the organic fertilizer mixture (35.53±3.22 cm) while the lowest length was recorded with the plants treated with the chemical fertilizers (18.96±2.12 cm).

b. Yield Parameters

There were significant differences among the fertilizer types for the fresh weights per fruit in the current experiment. Comparatively, a higher fresh weight was given by the organic fertilizer mixture (41.00±2.31 g) and Albert's solution (38.30±2.43 g) (Tab. 3). The lowest mean fresh weight resulted from the plants treated with chemical fertilizers (29.29±2.48 g). However, there were no significant differences in the fruit length among the tested fertilizer types. Comparatively, a higher fruit width was given by Albert's solution (3.39±0.12 cm) and a lower value was given by the chemical fertilizer (3.01±0.10 cm).

c. Total Number of Fruits Per Plant

The total number of fruits per plant was significantly different among the evaluated fertilizer types (Fig. 1). Comparatively a higher total number of fruits was recorded by the organic fertilizer solution (5.5 ± 0.68) while a lower number was recorded with Albert's solution + organic fertilizer mixture (2.5±0.58).

TABLE I. DETAILS OF EACH TREATMENT AND THEIR APPLICATION RATE

Fertilizer Type	Ingredients and application rates
Chemical Fertilizers (NPK)	Basal fertilizer – 1-2 days before planting (Urea-65, TSP-325, MOP-65 kg/ha) 1st Top dressing - 03 WAP (Urea- 65 kg/ha) 2nd Top dressing - 06 WAP (Urea- 65, MOP- 65 kg/ha)
Organic fertilizer mixture	200 ml per pot in weekly intervals as a soil drench.
Albert's solution + Organic fertilizer mixture	10 g of Albert's mixture was diluted in 4.5 L of water and 200 ml of solution was applied as a foliar spray per pot in weekly intervals. Organic fertilizer mixture was applied 200 ml per pot in weekly intervals.
Albert's solution	10 g of Albert's mixture was diluted in 4.5 L of water and 200 ml of solution was applied as a foliar spray per pot in weekly intervals.

TSP – Triple Super Phosphate, MOP – Muriate of Potash

TABLE II. EFFECT OF DIFFERENT TYPES OF FERTILIZERS ON GROWTH PARAMETERS IN TOMATO

Variable	Number of Leaves	Plant Height (cm)	Root length (cm)
Chemical Fertilizer	6.93 ± 0.28^{b}	81.73 ± 3.19^{a}	18.96 ± 2.12^{c}
Organic fertilizer mixture	10.27 ± 0.45^{a}	88.78 ± 1.76^{a}	35.53 ± 3.22^{a}
Albert's solution + Organic fertilizer mixture	9.37 ± 0.45^{a}	85.75 ± 2.57^{a}	22.47 ± 1.07^{bc}
Albert's solution	9.67 ± 0.67^{a}	88.22 ± 3.36^{a}	31.20 ± 2.44^{ab}

Values in each column represent the means of 5 replicates ± SE (Standard Error). The mean followed by the same letter within each column is not significantly different at $p<0.05$.

TABLE III. EFFECT OF DIFFERENT TYPES OF FERTILIZERS ON YIELD PARAMETERS IN TOMATO

Variable	Fresh Weight (g)	Fruit Length (cm)	Fruit Width (cm)
Chemical Fertilizer	29.29 ± 2.48^{b}	4.29 ± 0.21^{a}	3.01 ± 0.10^{b}
Organic fertilizer mixture	41.00 ± 2.31^{a}	4.84 ± 0.11^{a}	3.29 ± 0.10^{ab}
Albert's solution + Organic fertilizer mixture	36.37 ± 1.82^{ab}	4.73 ± 0.14^{a}	3.22 ± 0.08^{ab}
Albert's solution	38.30 ± 2.43^{a}	4.58 ± 0.17^{a}	3.39 ± 0.12^{a}

Values in each column represent the means of 15 replicates ± SE (Standard Error). The mean followed by the same letter within each column is not significantly different at $p<0.05$

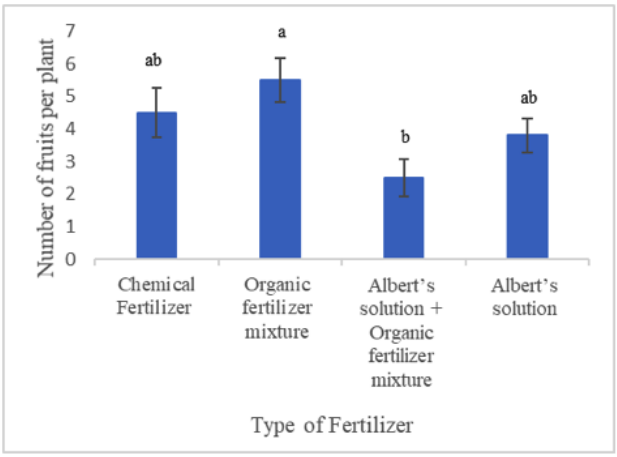

Fig. 1. Effect of different types of fertilizers on the total number of fruits per plant ($p<0.05$)

IV. Discussion

Based on the findings of the current experiment, the organic fertilizer mixture demonstrated superior performance in terms of several key parameters, including the number of leaves at 12 WAP, root length, and fresh fruit weights (Tables II and III). This enhanced performance may be attributed to the synergistic effects of the various components used in formulating the organic fertilizer solutions.

Cow dung, prominent agricultural manure, contains essential elements such as calcium (Ca), magnesium (Mg), sulfur (S), zinc (Zn), boron (B), copper (Cu), manganese (Mn), as well as the primary nutrients N, P, and K. Additionally, it contributes to improved soil structure by enhancing tilth, aeration, water-holding capacity, and fostering the growth of beneficial soil organisms. Cow dung has the potential to positively impact soil properties, including pH, cation exchange capacity, total N, organic carbon, exchangeable magnesium (Mg), and calcium (Ca) [4]. In many tropical and subtropical regions, *Gliricidia sepium* trees, a type of leguminous plant, are employed as living fences. The leaves of *G. sepium* are utilized for green manure and the production of various organic fertilizers due to their high nutritional content. Incorporating *Gliricidia* leaves into this experiment aimed to introduce additional nutrients. Reference [5] reported increased tomato production compared to NPK fertilizer, attributed to the presence of N, Ca, K, and P in *Gliricidia*. They also observed enhanced growth and fruit yield of tomatoes when *Gliricidia* was used as a green manure crop, recommending its use for increased tomato yields [5].

While banana leaves have various agricultural applications, their use as a source of plant nutrition has not been extensively studied. Banana peels, on the other hand, serve as highly effective organic fertilizers. As they decompose, banana peels release nutrients into the soil, including Mg, Ca, P, S, and K. The high K content in banana peels is particularly beneficial for fruit growth. The incorporation of banana peels during the reproductive growth phase of tomato plants likely contributed to the improved fruit characteristics observed (Table III). Eggshells also have potential as a fertilizer due to their Ca content, which is essential for proper tomato fruit development. Both K and Ca play vital roles in supporting healthy tomato fruit growth.

However, neither growth nor yield parameters exhibited significant improvements in plants treated with chemical fertilizers. It is a common observation that chemical fertilizers tend to outperform their organic counterparts [3]. Typically, NPK fertilizer recommendations are prepared for soil cultivation. However, the current experiment employed a soilless medium comprising sand and coir dust. Sand, characterized by its lower cation exchange capacity and reduced organic matter content, has limited nutrient retention capabilities compared to traditional soil. Conversely, the chemical fertilizers utilized in this experiment, while readily available, are more susceptible to nutrient loss from the system if they fail to adhere to the growing medium effectively. In contrast, the organic fertilizer solution featured a higher organic matter content, which facilitated nutrient adherence to the growing medium. Notably, the prevailing adverse weather conditions, including heavy rainfall, may have exacerbated the situation when chemical fertilizers were used, leading to nutrient loss through leaching, particularly with respect to N.

In comparison to previous studies [6], the current results revealed significantly lower fruit yields across all treatment groups (Fig. 1). It is essential to acknowledge that adverse weather conditions and the characteristics of the growth medium likely had detrimental effects on all treatments, irrespective of treatment effect. To further improve the current experiment, it is proposed to conduct it under controlled greenhouse conditions, employing the same growth medium. Additionally, performing the experiment as a plot trial in an open-field setting is recommended. These approaches will enable a more comprehensive investigation to determine the specific conditions under which organic fertilizer treatments can yield superior results. Such a comparative study will provide valuable insights into optimizing organic fertilizer applications for improved crop yields.

V. Conclusion

The current experiment was carried out in a setting where farmers lacked access to affordable chemical fertilizers. The major goal was to contrast the results of using various organic fertilizer sources as combined solutions with the way tomatoes are currently fertilized. The results of this experiment showed that when tomatoes are grown in pots with the use of sand and coir dust in open field circumstances, the use of organic

fertilizer combinations can increase the output of tomatoes compared to standard fertilizing procedures. To achieve better outcomes, the solution's formula must be altered in accordance with the plant's developmental stage. To attain the potential yield, the impact of the environment must be adequately managed in the interim.

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2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

Effect of Salinity Stress on Plant Growth, Yield, and Taste Components in Tomato (*Solanum lycopersicum*)

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***Abstract*—Tomato cultivation in Sri Lanka faces challenges due to salinity stress, and it affects productivity and quality. This study investigates the impact of salinity stress on tomato growth, yield, and fruit attributes. Three treatments were investigated which are T1: Control- level (0.6 g/l NaCl), T2: Additional - level (3.0 g/l NaCl), and T3: Excess - level (6.5 g/l NaCl). and plant growth, fruit parameters, and yield were analyzed. Plant height and leaf growth were decreased with time by excessive salinity stress, while fruit quality (pH) was increased. Yield per plant was affected, with excess salinity leading to lower yield (264.8 ± 13.6 g) while resulting in the lowest fruit weight (23.2 ± 0.27 g). These findings provide insight into how salinity stress affects tomato cultivation, which is important for sustainable agricultural practices. Notably, excess salinity improved fruit quality, despite adverse effects on growth and yield.**

***Keywords*—Salinity stress, growth parameters, yield, fruit length**

I. Introduction

Tomato (*Solanum lycopersicum*) is a highly valuable and widely cultivated crop across the globe. Environmental factors, especially the temperature, soil water conditions, and salinity have been found to alter the plant chemistry [1]. Especially, the productivity and quality of tomato plants are significantly affected by various abiotic stresses, including salinity stress. Salinity stress occurs when excessive salts accumulate in the soil, leading to hindered water and nutrient uptake by plants [2]. In regions like Sri Lanka, salinity stress is a critical factor that limits plant cultivation in saline-affected lands [1]. Salt tolerance is an important topic in agriculture to study because it causes the loss of plant productivity and land productivity by salinization. However, to our knowledge, findings about the salinity stress and the taste component behavior with the salinity were very limited, and therefore, this study aims to address the yield and taste components of tomatoes cultivated under different salinity stress conditions in Sri Lanka.

II. Methodology

The experiment was conducted in a poly house in Kadawatha, Sri Lanka, from January 2023 to May 2023. Tomato seedlings from the variety 'Thilina' which were three weeks old were planted in black color polythene bags. Three treatments were executed: T1: Control- level (0.6 g/l NaCl), T2: Additional - level (3.0 g/l NaCl), and T3: Excess - level (6.5 g/l NaCl). Salinity stresses were induced through the irrigation water and water treated with different levels of NaCl was applied to the plants once in two days until the end of the study. Plant Height (cm), and Number of Leaves were measured in weekly intervals and the Wet and Dry weights of the plants were measured at the end of the experiment. Harvesting was done when fruits reached their full maturity. Fruit length (cm), Fruit weight (g), Number of Fruits/Plant, Brix%, and pH were measured in the fruits harvested daily and finally, the Total Yield (g)/Plant was calculated. Each fruit sample was ground and juiced for Brix and pH analysis. Brix% was analyzed by a Refractometer and pH was analyzed by a Digital pH meter. Statistical analysis was carried out employing the ANOVA feature within the MINITAB Statistical Package, version 19. The study utilized a one-factor Factorial design with 18 replicates per treatment.

III. Results

The study investigated the effects of three salinity treatments on various plant growth, fruit, and yield parameters.

A. Growth Parameters

a. Plant Height

There were no significant differences noted among the treatments during the 1st and 6th week. However, control-level treatment plants showed higher values than additional-level treatment and excess-level treatment (Tab. 1).

b. Number of Leaves

There were no significant differences observed among treatments, but control-level treatment plants showed higher values than additional-level treatment and excess-level treatment (Tab. 2).

c. Wet and Dry weight

There were no significant differences observed among treatments, but excess-level treatment plants showed higher values than control-level treatment and additional-level treatment in terms of dry weight and control-level treatment showed higher values than the other two treatments in terms of wet weight (Tab. 3).

B. Fruit and Yield Parameters

a. Fruit Length

Significant differences among treatments were observed for fruit length. Control-level treatment plants had significantly wider fruits (12.0 ± 0.10 cm) compared to the other two treatments (Tab. 4).

b. Fruit Weight

Fruit weight exhibited significant differences between control-level treatment and additional-level treatment, as well as between control-level treatment and excess-level treatment (Tab. 4).

c. Number of Fruits/plant

Significant differences among treatments were observed for the Number of Fruits/plants. Control-level treatment plants had significantly more fruits (14.0 ± 0.9) compared to excess-level treatment (Table V).

d. Yield/Plant

Significant differences in yield were observed among treatments. Additional-level treatment had a significantly higher yield compared to excess-level treatment (Tab. 5).

e. Brix%

There were no significant differences noted between the treatments (Tab. 4).

f. pH

There were significant differences in pH between the treatments. In comparison to control-level treatments and additional-level treatments, excess-level treatments exhibited significantly higher pH values (Tab. 4).

TABLE I. RESULTS OF PLANT HEIGHT

Treatments	Plant Height (cm)				
	1st week	*4th week*	*6th week*	*8th week*	*11th week*
T1	71.9 ± 1.0 [a]	88.7 ± 1.0 [a]	91.0 ± 1.3 [a]	97.1 ± 1.2 [a]	102.8 ±1.2 [a]
T2	60.4 ± 5.2 [a]	71.8 ± 6.1 [ab]	77.0 ± 6.6 [a]	29.1 ± 2.5 [c]	86.5 ± 7.4 [ab]
T3	60.0 ± 5.2 [a]	68.6 ± 5.9 [b]	73.1 ± 6.3 [a]	77.5 ± 6.6 [b]	81 ± 6.9 [b]

Values in each column represent the means of 18 replicates ± SE (Standard Error). The mean followed by the same letter within each column is not significantly different at $p<0.05$

TABLE II. RESULTS OF THE NUMBER OF LEAVES

Treatments	Number of Leaves				
	1st week	*4th week*	*6th week*	*8th week*	*11th week*
T1	16.0 ± 0.4 [a]	25.5 ± 0.8 [a]	29.5 ± 1.0 [a]	31.3 ± 1.4 [a]	31.5 ± 0.7 [a]
T2	14.0 ± 1.28 [a]	23.10 ± 2.1 [a]	26.2 ± 2.4 [a]	29.1 ± 2.5 [a]	30.5 ± 2.8 [a]
T3	12.5 ± 1.22 [a]	20.8 ± 1.9 [a]	24.2 ± 2.1 [a]	27 ± 2.3 [a]	26.9 ± 2.4 [a]

Values in each column represent the means of 18 replicates ± SE (Standard Error). The mean followed by the same letter within each column is not significantly different at $p<0.05$

TABLE III. RESULTS OF GROWTH PARAMETERS

Treatments	Plant Growth Parameters	
	Plant Dry weight (g)	*Plant Wet Weight (g)*
T1	82.2 ± 2.6 [a]	184.3 ± 4.1 [a]
T2	71.0 ± 5.8 [a]	167.9 ± 15.2 [a]
T3	93.8 ± 7.6 [a]	169.2 ± 15.1 [a]

Values in each column represent the means of 18 replicates ± SE (Standard Error). The mean followed by the same letter within each column is not significantly different at $p<0.05$

TABLE IV. RESULTS OF FRUIT PARAMETER AND TASTE COMPONENTS

Treatments	Fruit and Yield Parameters		
	Fruit Length (cm)	*Brix%*	*pH*
T1	12.0 ± 0.10 [a]	4.1 ± 0.02 [a]	4.4 ± 0.04 [ab]
T2	11.3 ± 0.09 [b]	4.1 ± 0.04 [a]	4.3 ± 0.02 [b]
T3	11.1 ± 0.02 [b]	4.2 ± 0.03 [a]	4.5 ± 0.05 [a]

Values in each column represent the means of 18 replicates ± SE (Standard Error). The mean followed by the same letter within each column is not significantly different at $p<0.05$

TABLE V. RESULTS OF YIELD AND FRUIT PARAMETERS

Treatments	Fruit and Yield Parameters		
	Fruit Weight(g)	*Yield/Plant (g)*	*Number of Fruits*
T1	27.6 ± 0.38 [a]	386.1 ± 26.8 [a]	14.0 ± 0.9 [a]
T2	26.4 ± 0.25 [b]	342.0 ± 8.4 [a]	12.9 ± 0.3 [ab]
T3	23.2 ± 0.27 [c]	264.8 ± 13.6 [b]	11.3 ± 0.5 [b]

Values in each column represent the means of 18 replicates ± SE (Standard Error). The mean followed by the same letter within each column is not significantly different at $p<0.05$

IV. DISCUSSION

Abiotic stress, which includes conditions like drought, salinity, and high temperatures, has a detrimental effect on the growth, development, and yield of plants. This study

examined the effects of various salinity treatments on various characteristics of fruit and plant growth parameters and there were significant differences in terms of plant height during the 4th, 8th, and 11th weeks. In most of the weeks, excess-level treatments showed lower results compared to control and additional-level treatments and this behavior was similar in the Additional-level treatment plants which also showed lower results than control-level treatment. Even though there were no significant differences noted between the treatments, additional-level treatment, and excess-level treatment showed lower values when compared to control treatment in terms of the number of leaves. These findings align with other studies that indicate salinity adversely affects plant growth and development [2]. Excess-level treatment plants showed higher values than additional-level treatment in terms of plant dry weight and wet weight, suggesting excess salinity stress level might increase the moisture and dry matter content of plants. Excess level condition plants' Fruit number and yield per plant were lower than control-level treatment and additional-level treatment. This finding aligns with other studies that indicated decreased yield, and fruit number under saline conditions [3]. However, when comparing the yield per plant, the results of the additional-level condition with the control-level condition, there were only minor differences noted between the values, indicating that yields are only slightly or not at all affected by low salt concentrations [4]; [5]. Salinity, which is defined as an excessive level of salt in the soil, water, and plants, is an issue that can be caused by both natural and anthropogenic activity and gets more acute with time. Prior studies investigated how saline stress affected the development, production, and taste components of different crops [6]. While the Brix% values exhibited no significant differences, the pH values demonstrated variations, with excess salinity levels leading to elevated pH levels compared to the other two conditions. So, it appeared to enhance fruit quality. This aligns with previous observations that salinity stress can lead to improved fruit quality attributes, possibly due to altered metabolic pathways [3]. Along with this, a prior report showed the Fruit's glucose level increased while its total sugar and glutamic acid amounts decreased as the water supply in the fruit of Chili Pepper (*Capsicum annuum* L.) [7].

V. Conclusion

This research provides valuable insights into the effects of different salinity stress levels on various plant growth, yield, and fruit parameters. The results underline the potential negative impacts of salinity on plant height, leaf growth, fruit number, and yield, while also suggesting a potential positive effect on fruit quality. These findings contribute to our understanding of how salinity stress influences plant growth and fruit development and can guide strategies to mitigate its adverse effects on agricultural productivity.

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2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

Postharvest Losses and Quality Variations of Tomatoes in Wholesale Markets: A Case Study of Sri Lankan Supply Chain

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Abstract*—Reducing postharvest losses is crucial in enhancing food security by improving the affordability and availability of safe and nutritious food. In Sri Lanka, the tomato supply chain faces greater postharvest losses mainly during transportation to wholesale markets. This study was conducted with the objectives of recognizing both the quantitative and qualitative loss of the tomatoes in one major wholesale market, in Sri Lanka, "Peliyagoda" sourced from different regions in Sri Lanka, and to recognize the reasons/ postharvest practices affecting such differences. Wholesale boxes of tomatoes from three major tomato growing areas in Sri Lanka, "Suriyawewa", "Balangoda" and "Kurunegala" were purchased from the "Peliyagoda" wholesale market and quantitative loss was assessed as a percentage of unmarketable tomatoes. They were further categorized as physical damage, physiological damage, and pathological and entomological damage. Then, the tomatoes of each box were analyzed for their qualitative parameters such as weight, color, firmness, and total soluble solids along with the shelf life of the tomato. Our results indicated that 22%-33% of postharvest losses occur across these regions, primarily due to physical damages (18%-20%). Box 2 and 3 from Balangoda and Kurunegala, harvested during the rainy season, experienced higher losses (10%-13%) due to physiological damage. Quality losses, including color change, firmness loss, and shorter shelf life (12 days), were prominent in improperly sorted boxes from Suriyawewa which contained >50% light red to red tomatoes. Future studies should extend the analysis throughout the supply chain, aiming to identify the root causes of these losses and enhance food security through facilitating necessary interventions. Keywords— Postharvest losses, tomato supply chain, food security, qualitative analysis, Sri Lankan market

I. INTRODUCTION

Food security is a global concern which is greatly influenced by postharvest losses. Reducing postharvest losses is essential in minimizing food loss, enhancing food availability, and retaining nutritional quality, thus individuals have access to safe, sufficient, and nutritious food, aligning with broader food security objectives.

Tomato (*Solanum lycopersicum* L.) is one of the most popular commercial crops and the most produced vegetable in the world with a production of approximately 189.1 million metric tonnes [5]. Tomatoes contain essential vitamins, minerals, fiber, protein, amino acids, monounsaturated fatty acids, carotenoids, and phytosterols thus have numerous health benefits including the prevention of constipation, the lowering of high blood pressure, maintaining of the lipid profile and, the detoxification of toxins [1]. Furthermore, tomatoes are a valuable source of bioactive compounds that help in the prevention of cardiovascular disease (CVD), cancer, and neurodegenerative diseases. In Sri Lanka, where tomato production reaches around 90 thousand metric tonnes [5], tomatoes are commonly grown across diverse agroecological regions well-suited to their cultivation. However, Sri Lankan tomato value chain faces a significant challenge, in the form of high postharvest losses (PHL) which range between 40-60%.

Postharvest losses can occur at any phase along the food supply chain during handling, storage, transportation, and processing [2]. In Sri Lanka, a significant portion of the losses occur during transportation of tomatoes between the farm gate to the wholesale market [3]. When considering the high transporting expense, wholesalers often overload the produce and improper practices such as siting and sleeping on the poly-sacks in which fruits and vegetables are securely packed during transportation, rigorous handling while loading and unloading, cause substantial mechanical injuries to fresh products [3]. Also, various other factors like physiological breakdowns, diseases and insect pests [1], improper transportation facilities, inappropriate packaging, exposure to unfavorable temperatures, RH and gaseous environment, lack of appropriate tools, equipment and technology significantly influence the postharvest losses of tomato [3]. These factors collectively lead to decreased quality, weight loss, reduced nutritional value, decreased consumer acceptability, and ultimately, economic losses

with increased environmental impacts [3]. To reduce these losses, it is essential to first quantify these losses and identify the causes of quantitative and qualitative losses. In developing countries, concerns about reducing quantitative losses (i.e., weight, volume, or total wastage of agricultural produce) generally take more attention over qualitative losses such as loss of edibility, nutritional quality, caloric value, and consumer acceptability of the produce [1]. It is also widely acknowledged that qualitative losses are far more difficult to evaluate than quantitative losses [1].

Therefore, in this study, we aim to recognize both the quantitative and qualitative loss of the tomatoes in Sri Lanka's one of the major wholesale markets, "Peliyagoda" wholesale market from different origins, to recognize the reasons or postharvest practices affecting such differences and to recognize the quality parameters that contributed to the postharvest loss.

II. METHODOLOGY

A. Experimental Site

The study was conducted in the 'Peliyagoda' wholesale market (Previously known as _Manning Market) (6° 57' N to 79° 52' E, 7 m.a.sl). Purchased tomato boxes' information is mentioned in the Table I. The boxes belonged to three major tomato growing districts in Sri Lanka; Suriyawewa, Balangoda and Kurunegala. All three boxes were packed in corrugated cardboard boxes and purchased within the period of 19th July to 25th September 2023. Maximum temperature, rainfall and humidity data for each location when produce was at farmgate. Suriyawewa recorded the highest maximum temperature at 33°C, followed by Balangoda and Kurunegala, both at 32°C. Balangoda had the highest relative humidity at 80%, while Suriyawewa had 76%, and Kurunegala had 78%. Rainfall data showed that Balangoda experienced the most rainfall with 30 mm, in contrast to Kurunegala's 1 mm and Suriyawewa, where there was no recorded rainfall. Upon reaching Peliyagoda, box 2 faced a higher level of rainfall (15mm) compared to the box 3 (0 mm) and box 1 (0 mm). Quality evaluations were carried out in the Botany Research laboratory, at the Open University of Sri Lanka, Nawala, Sri Lanka. (6°54′N to 79°53E, 9 m.a.sl).

TABLE I. WEATHER PATTERNS AT FARMGATE AND WHOLESALE MARKET LOCATIONS

Box	**Box 1**	**Box 2**	**Box 3**
Date	17/08/2023	14/09/2023	25/09/2023
Type	CFB[a]	CFB	CFB
Location	Suriyawewa	Blangoda	Kurunegala
Temp. (C°)	33	32	32
RH (%)	76	80	78
RF (mm)	0	30	1
Peliyagoda Temp (C°)	31	30	31
Peliyagoda RH (%)	78	80	78
Peliyagoda RF (mm)	0	15	0

[a]CFB= Corrugated fiberboard boxes

B. Quantitative Assessment of Marketable and Unmarketable Tomatoes

Total weight of the tomatoes in the box was measured. Unmarketable tomatoes were separated and categorized as; due to physical damage (cuts, punctures, bruises, scratches, slits, crushes, abrasions, and cracks), physiological damage (wilting, shrinkage, heat stress, cuticle cracks, puffiness, craft facing and internal breakdown) and pathological and entomological damage (Fungi and bacteria, infestation by trips, white flies and mites). Their weights were taken separately and postharvest loss% (PHL%) was calculated according to following equation.

$$\text{Postharvest loss (\%)} = \frac{\text{Weight of unmarketable tomatos (kg)} \times 100}{\text{Total weight of tomatoes (kg)}}$$

Next, marketable tomatoes were weighed and divided into six stages as mature green, breaker, turning, pink, light red and red according USDA classification. Weight of the tomatoes at each stage of maturity was also expressed as a percentage from the total weight.

C. Qualitative Assessment of Tomatoes

In each of the maturity stages,10 tomatoes were selected for analysis. Where there were fewer than 10 tomatoes available at a particular stage, all the available fruits were included in the study. Fruits were analyzed for the following quality parameters.

Average weight (g) of a tomato was taken using scale (OHAUS, PA413).

Color (L*, a* and b* tri stimulus values) of tomatoes were taken at two opposite sides using the mobile `Color Meter` app © (version 1.0.3). Firmness was measured at two opposite points on the equator of each fruit; one side was measured with skin and the other side, a thin (<1mm) skin was removed using a sharp knife and the firmness was measured using digital penetrometer (AGY-15, China).

To measure the TSS content of tomato, a few drops tomato juice was obtained from crushing tomato fruits separately using a hand squeezer and measured using the refractometer [Model, WZ-113, China (Mainland)] Results were expressed as °Brix.

Shelf-life assessment was conducted for ten tomatoes from each maturity stage stored under room temperature. The number of days to reach unmarketable state for each fruit were noted.

D. Statistical Analysis

Qualitative data were subjected to statistical analysis with a completely randomized design (CRD) consisting two factors; Box, maturity stage and their interaction effects were identified using two-way analysis of variance (ANOVA) at the 5% confidence interval. All statistics were carried out using SPSS statistical program (IBM SPSS Statistics for Windows, Version 22.0. Armonk, NY).

III. Results and Discussion

A. Quantitative Assesment of Tomatoes

Among three tomato boxes analysed, (Box 1 – Suriyawewa, Box 2 – Balangoda and Box 3 – Kurunegala), Box 2 had the highest average fruit weight of 68.019g, while Box 1 and Box 3 had average fruit weights of 35.82g and 30.89g, respectively. It's worth noting that these variances in tomato weight may be attributed to the tomato cultivars cultivated in each respective district. Highest marketable fruit percentage (78.30%, w/w) was obtained from box 1 (Table II). Box 2 and Box 3 exhibited similar percentages of marketable tomato quantities, standing at 67.30% and 66.98% (w/w), respectively. In all three boxes, tomatoes were found in various maturity stages, mature green, breaker, turning, pink, light red and red, and there was no apparent sorting applied to the bulk tomato boxes. Notably, Box 2 and Box 3 had most tomatoes in stages 2, 3, and 4, whereas Box 1 had tomatoes of latter four stages (Stages 3, 4, 5, 6), as indicated in Table II. Tomatoes in the red stage are fully ripped and their tissues are softer than the tomatoes in green stage. So, when tomatoes in green and red stages are stacked together, ripened tomatoes are more prone to mechanical damages and compression damages during transportation [3]. Therefore, it is advised to harvest tomatoes at breaker stage and follow proper sorting to minimize postharvest loss in the value chain.

However, Box 2 and Box 3 showed relatively higher postharvest losses (PHL), around 32.74% and 33.02% (w/w) respectively, as indicated in Table II. In contrast, Box 1 displayed a comparatively lower PHL of 21.70% (w/w). Therefor0e, improper sorting/ inclusion of more red stage tomato may not be the reason for higher quantitative losses. Upon conducting a thorough analysis of the factors contributing to losses, it was evident that physical damages resulted in nearly equivalent losses for all three boxes, with postharvest loss percentages (PHL%) of 19.03% for box 1, 17.89% for box 2, and 20.40% for box 3. Notably, the issue of physiological damages showed more losses in box 2 (12.76%) and box 3 (10.88%), whereas box 1 exhibited a significantly lower rate of 0.66%. The uniformity in physical damage levels and the same packaging system (CFB) and transportation via lorries suggest that the adverse conditions in the tomato harvesting, packing, and handling procedures across the districts are a common factor.

However, the distinctive weather patterns prevailing in each geographical region emerged as a critical determinant in the extent of losses attributed to physiological damages. For instance, box 1 contained tomatoes grown in the dry zone and harvested during the dry season, whereas box 2 and box 3 contained tomatoes from the wet and intermediate zones, respectively. The rainy season after a dry spell can increase physiological damages to tomatoes. Elevated humidity levels and temperature fluctuations in the growth period can lead to issues such as wilting, cuticle cracks, puffiness, and internal breakdown which explains the higher postharvest losses in box 1 and box 2 due to physiological damages. Such weather conditions also facilitate fungal and bacterial pathogens.

TABLE II. Quantitative Postharvest Loss

	Box 1 (Suriyawewa)	**Box 2 (Balangoda)**	**Box 3 (Kurunegala)**
Average fruit weight (g)	35.82[a]	68.019[b]	30.89[a]
Marketable %	78.30%	67.30%	66.98%
Mature green	0.50%	0.85%	1.64%
Breaker	2.67%	23.65%	25.02%
Turning	14.36%	16.54%	16.43%
Pink	29.72%	15.31%	20.32%
Light red	13.69%	8.95%	3.45%
Red	39.07%	1.95%	0.11%
PHL %	21.70%	32.74%	33.02%
Physical damage %	19.03%	17.89%	20.40%
Physiological damage %	0.66%	12.76%	10.88%
Pathological damage %	2.00%	2.08%	0.92%

[a]Values followed by different superscript letters are significantly different within a row according to Tuckey test ($p < 0.05$).

B. Qualitative Assesment of Tomatoes

Tab. 3 shows the results of the qualitative assessment. According to the results of color measurement, stage of maturity has significant effect on colour development. When transitioning from mature green to red stage, L* tend to decrease, a* increase and b* showed no consistent trend (data not shown). L* value in the tomatoes of each wholesale box ranged between 38.5 to 47.38.

CIELAB (Commission Internationale de l'Éclairage) method is the most commonly used method for food color measurement as it closely approximates the color perception of humans [4]. In this system, L* denotes the degree of darkness to lightness from black to white (L* = 0 to 100), while the a* axis shows the greenness to redness on a scale of -100 to +100. Parameter b* provides an approximation of the yellowness and blueness on an array of colors from yellow (a positive number) to blue (a negative number) [4]. In both commercial practice and scientific literature concerning tomato fruits and their derivatives, the a*/b* ratio has emerged as a widely utilized reference criterion for assessing color quality [4]. The a*/b* ratio of immature green tomatoes is < 0; when the tomatoes ripen and get more reddish color, it rises to 0 and above [4]. Correspondingly, it was observed that all three tomato boxes in our study exhibited a*/b* ratios exceeding 0, with box 2 standing out as having a significantly lower a*/b* ratio. Furthermore, our analysis revealed that box 2 showcased significantly highest L* value implying box 2 mainly held less ripened tomatoes, finding that also aligns with our quantitative analysis results.

When considering the obtained values for firmness, maturity stage had significant influence but not the box. However, tomatoes from "Suriyawewa" area had the lowest peel firmness of 4.77 N (Table III), while tomato grown in "Balangoda" and "Kurunegala" areas showed nearly an equal firmness value which is higher than the firmness of tomato in box 1. Tomatoes in all three boxes showed approximately same firmness without skin and it ranged between 3 N - 3.5 N. High respiration rate, moisture loss through transpiration, senescence, and disintegration of the tomato cell wall during ripening linked to the decrease in firmness of tomato [2]. Tomato peel act as a barrier to most of the micro-organisms and when the peel firmness is low or damaged the loss is higher.

The mean TSS values ranged in following order, box 2 (4.62) < Box 1 (4.69) < box 3 (4.74) without any significant difference. Stage of maturity had significant effect on TSS development. During ripening, pectin substances in tomato fruit breakdown into simple sugars [2]. This degradation leads to the increase in the TSS content. Highest TSS value can be observed in the red stage while mature green stage shows the lowest TSS value.

Tomatoes were stored under 25°C, RH, for 14 days. Tomatoes from Suriyawewa area showed significantly lower shelf life and it was nearly 12 days while Box 2 (Balangoda) and box 3 (Kurunegala) exhibited around 13 days shelf life. This variation may have occurred due to containing unsorted and higher proportion of red maturity stage (39%) tomatoes in box 1 which has led to gradual deterioration of quality and shorter shelf life. Also, it is worth noting that shelf life may further decline in the actual retail conditions where tomatoes are roughly handled and stored in less ventilated spaces, compared to the laboratory conditions.

TABLE III. QUALITATIVE POSTHARVEST LOSS

		Box 1	Box 2	Box 3	Significance		
					(B)	*(S)*	***(B*S)***
Color	**L***	38.50[a]	47.38[b]	40.84[a]	*	*	*
	a*	24.14	20.95	25.90	ns	*	*
	b*	44.37	45.54	44.05	ns	*	*
	a/b	0.59[a]	0.45[b]	0.62[a]	*	*	*
Firmness	**F_s**	4.77	5.37	5.54	ns	*	ns
	F_f	3.03	3.40	3.06	ns	*	ns
TSS		4.69	4.62	4.74	ns	*	*
Shelf life		11.85[a]	12.98[b]	13.16[b]	*	*	*

[a] Values followed by different superscript letters are significantly different within a row according to Tuckey test ($p < 0.05$).

IV. CONCLUSION

In conclusion, our comprehensive assessment of tomato wholesale boxes from different regions; Suriyawewa, Balangoda, and Kurunegala has revealed significant variations in both quantitative and qualitative aspects, offering valuable insights on factors affecting tomato quality and postharvest losses. Our findings revealed differences in the quantitative loss with Box 1 showing the highest marketable percentage, which implies potential influences of local weather conditions in tomato production on physiological damage. Our study underscores that sorting practices and fruit maturity significantly affect qualitative postharvest losses, affecting attributes such as tomato color, firmness, TSS levels, and ultimately shelf life. The notably higher average fruit weight in Box 2 from Balangoda suggests potential disparities in tomato cultivars among regions as a contributing factor. This research provides a foundational understanding of postharvest losses in the wholesale tomato market in Sri Lanka. To further the findings, future studies should encompass the entire value chain, tracking tomatoes from the farm level to the wholesale market over an extended time period even though the load tracking methodologies are challenging due to economic constraints. Obtaining more representative samples could be helpful in drawing insights on the root causes of postharvest losses, facilitating the implementation of interventions to enhance food security.

ACKNOWLEDGMENT

This work was supported by the Australian Center for International Agricultural Research (ACIAR) under Grant CS/2020/193.

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2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

Comparison of Trained, Untrained, and Consumer Sensory Evaluations in Raw Fish and Fish-Based Products: A Review

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***Abstract*—This review summarizes sensory evaluations (trained and untrained) and consumer preference research as a key part of developing new products, particularly raw and processed finfish and shellfish products. A comparison of the differences between panel results will be a perfect guide to identifying the drawbacks in sensory quality acceptance while improving fish-based food products and raw food fish items. Furthermore, assessing the novel products' quality and commercial feasibility is important before reaching consumers. According to the final interpretation, in most cases, trained panelists and untrained/consumers exhibit similar attitudes toward the overall acceptability of raw fish and fish-based products. However, when concerning in-depth sensory profiles of various raw fish and fish-based products, it's clear that sensory experts showcase different perceptions than untrained panelists and consumers. This represents the different perceptions of flavor, texture, aroma, and taste attributes because trained panelists evaluate such qualities following a scientific procedure. However, consumers depend on their preferences and giving scores. Therefore, results for such sensory attributes are not always the same for both panel types. Besides, consumer attitudes toward fish-based products are significant when introducing novel products. Professional testing and assessment sometimes fail to replace hedonic tests, resulting in food product failures. Analyzing consumer attitudes, behaviors, and emotions is a crucial aspect of these novel developments to understand the complicated consumer-product interaction. Finally, this review will aid in a better understanding of selecting the most appropriate sensory approach to raw and fish-based new product development for researchers/producers.**

Keywords—Descriptive panel, consumer preference, sensory evaluation, Fish products, hedonic responses, sensory attributes

I. INTRODUCTION

The use of the human senses for measuring and interpreting sensory characteristics of food, beverages, or other materials is defined as sensory evaluation [1]. The different types of panels with different sensory qualifications can be distinguished depending on their role. A trained panel comprises selected and trained assessors who have undergone training and have experience with the methods under investigation [2].Randomly selected potential customers of the target markets who haven't received any training represent untrained and consumer panels. Different types of sensory evaluation methods are performed depending on the type of panel.

Past research work witnessed, as in [3] some of the sensory evaluations by trained panels haven't represented consumer preference. Whereas the market surveys demonstrate the huge potential of consumer rejection of novel fish-based products. Therefore, it's vital to consider consumer preference before introducing new products into the market for better profit gain. This review will describe the fluctuations between trained, untrained, and consumer panel results on ready-made and semi-processed finfish and shellfish products.

The objectives of this review is to compare the relationship between the sensory evaluation results with the type of panel concerning raw fish and fish-based products.

II. RESULTS

This study compares the differences between the sensory evaluation results of processed/cooked finfish products, processed/cooked shellfish products, and raw or fresh finfish/shellfish food items, using three main panel types including trained/expert panelists, untrained panelists, and consumer panelists. Final sensory interpretation differs because of the knowledge and experience variations in the type of panel involved.

A. Cooked/Processed Finfish Products

Both types of panels showcase similar attitudes toward the overall preference. Flavor is the major attribute that determines preference. Both trained panelists and consumers exhibited the same opinion regarding the flavor attribute. But almost all the other attribute ratings are different for experts and consumers.

According to the previous research findings, both trained panelists and consumers exhibited the exact same answers when concerning overall preference. In most of the cases, the food product that scored highest for the flavor attribute became the most preferred. It's evidence to prove that the flavor of a finfish product is the main attribute that will decide its overall acceptance. But such findings need more research. Also, it can be clearly identified that in most cases both trained panelists and consumers show similar attitudes when it comes to the flavor attribute of a particular cooked/processed finfish product (Margrethe et al., 2004).

However, there were significant differences between other attribute scores given by both types of panels especially in aroma, smoke intensity, and in texture. Consumers, they just can detect the most preferred food item. However, trained panelists were able to evaluate each and every sensory attribute in detail even identifying its slight changes.

In case there were some products that scored higher values for flavor, having lower values for aroma and texture (Agustinelli, M.I., S.P.and Yeannes,2015)(Diomar, Izabela, Sila, Helena 2015).

When developing new products, it is crucial to think about drivers of liking, smoking temperature, concentrations of the added ingredients, prior processing method (fresh/frozen), processing method (mincing), and post-processing method (chilling). Overall every study discussed the preference of each type of food product in many conditions, (Ex: smoked mackerel fillets in different temperatures) (Agustinelli, M.I., S.P.and Yeannes, 2015) concerning detailed sensory profiles including many sub-attributes which come under the main sensory attributes (Ex: texture- hardness, crunchiness, cohesiveness, glossiness, juiciness, etc.) (Margrethe et al., 2004). Therefore, the most accurate data were derived. If samples were served in 2/3-time replicates, getting the average score, will avoid random errors, when in the process of aiming to derive more accurate data. When comparing flesh quality, both GIFT and Red Tilapia show similar characteristics, as proved by trained panelists and consumers. But texture properties were differently understood by both types as trained panelists gave higher scores for chewing ability for GIFT while it received lower scores for texture from the consumers. According to the trained panelists, the general acceptability for GIFT is higher than for Red Tilapia (Khaw et al., 2006).

B. Cooked/Processed Shellfish Products

Trained panelists and consumers do not agree with attribute-wise ratings. Despite this, both types of panelists agreed that utilization of modern technological advances, when in product development, could enhance the sensory quality of shellfish products.

According to the research paper, both types of panels agreed that cryoprotectants and polydextrose/sucrose treatments can enhance the sensory quality attributes of frozen blue crab meat when in the preservation process (Henry, Boyd, Green, 1995). If taken in detail, appearance, odor, flavor, texture, and overall acceptability are significantly different for samples treated with cryoprotectants and polydextrose/sucrose than the pasteurized and control samples (p<0.05 and p<0.01) (Henry, Boyd, Green, 1995). Cerbas, 2022 stated that formulated crab balls had higher acceptability than commercial squid balls maybe because of their unique flavor and delicious taste. Also, the study suggested that blue swimming crabs can be used as an alternative solution when preparing fishery meatballs as it has a huge potential for commercialization. But shelf-life stability should be a concern as it affects the flavor, texture, and color (Cerbas, Jumdain, Tahiluddin, 2022).

Fish is a very perishable product, its sensory characteristics, especially texture attributes (like) of farmed Cod products can vary due to the stress level before slaughtering. Other factors affecting sensory quality include storage period, storage temperature, and preparation procedure (Sveinsdottier et al., 2009). Central Location Tests (CLT) gave similar results with trained panelists as both groups identified that highly stressed cod products were more tender and juicy than the low stressed cod products which were more meaty and rubbery in texture. The two sample types were only different with regard to texture attributes. This suggests that juicy and soft textures are desirable attributes in farmed cod. However, consumers who participated in the Home-Use Tests (HUT) didn't identify any difference between the two types of samples and gave higher overall liking scores for both types, highlighting the significance of the cooking method when developing the final sensory quality attributes. In addition to lower costs and less time-consuming procedures, CLT is the most accurate method to evaluate consumer preference (Sveinsdottier et al,2009).

C. Raw/Fresh Finfish or Shellfish Food Items

Salinity level should be the main concern. As it affects the sweetness, saltiness, umami value & aftertaste of the raw food item, also plays a major role in the overall acceptability. According to both types of panelists, the most preferred raw food fish items are from marine environment/marine farm-raised. Other concerns should be on storage condition and storage duration, freshness, and appearance.

When raw/fresh, finfish or shellfish items were taken into account, their sensory attributes were affected by salinity level, storage duration, and storage temperature (Shijie et al., 2021). However, when concerning the panel preference, both trained panelists and untrained/consumers showed similar results in overall acceptability. Salinity level should be a concern because it directly affects food's saltiness, aftertaste, and marine taste of food. Storage duration and temperature should be a concern because they cling to the color and texture of raw/fresh shrimp (Sivarajan et al., 2015). It's suggested that sweetness and umami value can play a major role in the overall acceptability of a raw/fresh finfish or shellfish product (Shijie et al., 2021). However, this finding must be proved with more research data.

Both trained panelists and untrained/consumer panelists prefer saltwater farm-raised fish than freshwater farm-raised and wild-caught fish. Therefore, there is a huge potential to develop marine aquaculture replacing conventional capture fisheries. Aquaculture has been successfully applied to a variety of seafood in many countries. Aqua-cultured fish in marine water have been highly preferred to the freshwater aqua-cultured species as they were less earthy/musty in flavor and highest in sweet and salty intensity (S.L. Drake, M.A. Drake, Daniels, Yates, 2005). This was the main difference between fresh water and marine water cultured fish as most probably all the other attributes are similar in both as there is natural variability in texture among fish because of many factors such as age and activity. It was found that fish with a lower fat content and/or smaller in size might have a lower level of earthy/musty flavor. High-intensity earthy flavor in freshwater-farmed fish can be purged by depuration, although it takes time. Consumer choice was influenced by the flavor and freshness of fish and consumer acceptance of flavor was the most significant determinant of white fish acceptability (Erickson, Bulgarelli, Resurreccion, Vendetti, Gates, 2006).

TABLE I. COMPARISON OF TRAINED, UNTRAINED, AND CONSUMER SENSORY EVALUATIONS IN FINFISH/SHELLFISH PRODUCTS AND FINFISH/SHELLFISH RAW OR FRESH FOOD ITEM

Processed/ cooked product	**Types of samples**	**Concerned sensory attributes by the trained panelists**	**Concerned sensory Attributes by the consumers/untrained panelists**	**Interpretation**	**References**
Smoked Mackerel Fillets	At two different temperatures (22celsius & 28celsius)	Aroma Flavor	Overall Liking	Both types of panelists showed the same attitude towards flavor, but different perceptions on aroma and smoke intensity.	(Agustinelli, M.I., S.P.and Yeannes ,2015) (Diomar, Izabela, Sila, Helena 2015)
Canned European Eels (*Anguilla anguilla*)	3 types of filling mediums - Sunflower oil - Olive oil - Spicy olive oil	External aspect Texture in mouth Aroma Taste	Flavor Aroma Texture Appearance General appreciation	According to the consumers canned eels packed in sunflower oil achieved the highest scores followed by the spicy canned eels. However, when concerning training panel results, cannot identify a particular order of ranking as different types of samples had the highest scores when concerning different attributes.	(Gomez-Limia, Carballo, Miriam & Sidonia, 2022)
Low Sodium Fish Burgers	Eight formulations	Appearance Aroma Flavor Texture	Appearance Aroma Flavor Texture Overall impression	Both trained panelists and consumers had the same attitude toward aroma and flavor. But different perceptions on texture.	(Diomar, Izabela, Sila, Helena, 2015)
Crab balls from Blue Swimming Crab (*Portunas pelagicus)*	Formulation A Formulation B Formulation C	Flavor Color Texture (juiciness & chewiness) General acceptability	General acceptability	According to the training panelists, formulations B & C showed the highest sensory scores compared to commercial products. However, consumers highly accepted the Blue Swimming Crab balls, regardless of formulation type than the existing general commercial products.	(Cerbas, Jumdain, Tahiluddin, 2022)
Pacific Oyster (*Crassostrea gigas*)	Farmed in 3 different salinities (25%,28%,32%)	Sweetness Saltiness Umami Bitterness Fishiness After taste Marine taste Overall taste	Acceptability of the oysters' taste	The highest umami value (4.0) and highest sweetness value (3.8) were recorded for 28%salinity level, by the trained panelists. Therefore, most acceptable salinity value was shown as 28% by both trained and consumers. But the highest saltiness (3.6), after taste (3.5), and marine taste (4.5) were recorded for 32% salinity level by trained panelists.	Shijie et al., 2021
High-Pressure Processing on Aquatic Products	-	Appearance Texture Odor Flavor	Appearance Texture Odor Flavor	Consumers cannot identify sensory differences at low-pressure levels (300-600Mpa) but experts are aware of the slight difference even in low-pressure levels. Both types can distinguish sensory differences in high-pressure levels.	(Chen, Wang, Zhang & Liu, 2022)
Ready-to-Eat Gulf Brown Shrimp	At three temperatures (63,85,93 Celsius) Packaged in air Vacuum conditions Modified Atmosphere packaging (MAP)	Fishy Cardboard Briny Oxidized Sulfury Eggy Metallic Chlorine Freshness	Aroma	Both consumers and experts preferred 85celsius vacuum and 85celsius MAP to the air treatment at any temperature.	(Kamadia, Schilling & Marshall, 2013)
Sensory differentiation of fresh Shrimp *(Penaeus sp.)*	Georgia Brown Gulf white Gulf brown Gulf pink Burma tiger Columbia white Belise white Honduras white Mexican white Georgia white	Raw aroma Raw meat appearance Raw shell appearance	Old shrimp aroma Shell glossiness Blotchiness Shell brown color Shell darkness Meat brown color Seawater aroma	Trained panel assessment revealed significant differences in all raw attributes, they were always associated with appearance. Also, notable differences occurred in aroma and in basic taste attributes. Significant differences were noted by the trained panel between fresh and commercially available frozen shrimp. However, consumers only identified differences in appearance attributes between the ten species of shrimps.	(Erickson, Bulgarelli, Resurreccion, Vendetti, Gates, 2006)

Frozen shrimp had greater intensities of cooked shrimp flavor and aroma though fresh shrimps were characterized as being sweeter and juicier than frozen shrimp. Freezing can enhance flavor and aroma while textural changes can be detrimental. Appearance attributes were the only characteristic that could be used to distinguish commercially available shrimp in the market. The duration of the storage period can affect the sensory attributes of the raw shrimp. Consumers purchased raw shrimp relying on the cooked characteristics of shrimp. Such attributes are glossiness, cooked color, seawater aroma, bitterness, meat plumpness, and meat brown color. Significant differences were noted by the trained panel between fresh and commercially available frozen shrimp. In terms of appearance, raw and fresh shrimps were glossier than raw and frozen shrimp but the loss in tail iridescence was the most notable difference in appearance for the raw product (Erickson, Bulgarelli, Resurreccion, Vendetti, Gates, 2006).

III. CONCLUSION

This review summarized the influence of both trained panelists and consumers/untrained panelists in fish-based products and raw/fresh finfish/shellfish food items. Both types of panelists are in consensus when it comes to overall acceptability. However, when concerning descriptive sensory profiles, experts are exhibiting more knowledge of sensory attributes than consumers. Therefore, it's better if both panels' opinions are taken when introducing a novel fish-based product. Overall, such information will be indispensable for the future of the aquatic food industry, for the researchers and undergraduates in their study purposes.

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2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

Development and Evaluation of Cinnamon (*Cinnamomum zeylanicum* Blume) Bark Oil-and Cinnamon Powder-Incorporated Pumpkin Cookies

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Abstract*—Cinnamon (*Cinnamomum zeylanicum*) is a tropical spice crop belonging to the family Lauraceae. It is used as a spice; there is a lack of value-added cinnamon-incorporated food products in the local market as well as in foreign markets. Pumpkin is an abundant tropical vegetable that contains vitamins, minerals, carotenoids, and fibers. This study aimed to develop cinnamon-incorporated pumpkin cookies with high nutritional qualities, identify physicochemical characteristics, and evaluate the sensory attributes. A 4:1 ratio was selected as the best ratio wheat flour supplementation with pumpkin flour. Cinnamon bark oil was incorporated into cookies in three different concentrations (0.1%, 0.3%, and 0.5%) and the best formulation was selected through sensory analysis with 30 untrained panelists. The cinnamon powder was incorporated into cookies in three different concentrations (2%, 4%, and 6%), and the best formulation was selected through sensory evaluation. For the sensory analysis, seven-point hedonic scales were used. Based on sensory results, 0.1% cinnamon oil and 2% powder-incorporated cookies were selected. Physicochemical characteristics were tested for the best two selected products and control (pumpkin cookie without adding cinnamon) samples. Powder-incorporated cookies contained 3.01% moisture, 3.19% protein, 27.92% fat, and 1.42% ash. Bark oil-incorporated cookies had 2.67% moisture, 3.27% protein, 26.88% fat, and 1.39% ash. The highest antioxidant activity was detected in the powder incorporated pumpkin cookies. The selected two products and control samples were evaluated in shelf-life studies using moisture, water activity, pH, colour, titratable acidity, and yeast and mold count, at two-week intervals, up to two months. Cinnamon bark oil and powder can be incorporated into pumpkin cookies to enhance flavour and physicochemical properties.

Keywords—Cinnamon powder, Cinnamon oil, Cookies, New products, Pumpkin flour

I. INTRODUCTION

Cinnamon is a tropical evergreen spice crop which belongs to the Lauraceae family. Sri Lanka is the origin of Ceylon cinnamon (*Cinnamomum zeylanicum* Blume). The Cinnamon plant's bark, leaves, and roots can be mainly used for a variety of beneficial applications. It contains an abundance of bioactive substances with anti-inflammatory, antimicrobial, and antioxidant properties. The main components are, respectively, cinnamaldehyde, eugenol, and camphor.

Pumpkins are widely grown in tropical and sub-tropical countries. Pumpkins belong to the Cucurbita genus and Cucurbitaceae. Rich in carotenoids, vitamins, minerals, dietary fibers, phenolics, polysaccharides, and pectins, it contains a high amount of β-carotene.

In Sri Lanka, the bakery industry is considered one of the main parts of the food processing sector. Cookies are a significant, widely consumed bakery product in the food industry. Cookies are prepared from wheat flour, fat, sugar, baking soda, and flavoring agents. Cookies may be further enriched by the incorporation of different ingredients and changing their rations. In this study, cookies were made with wheat flour and pumpkin flour and incorporated with cinnamon bark oil and powder. It enhances the nutritional value, colour, flavour, texture, rheological and sensory properties of cookies.

II. METHODOLOGY

A. Location

This research was carried out at the National Cinnamon Research and Training Centre, Department of Export Agriculture, Palolpitiya.

B. Collection of Raw Materials

All the raw materials were collected from the Matara market. The ground cinnamon, cinnamon bark oil and packaging materials were collected from the Research Institute.

C. Preparation of Pumpkin Powder

Fresh, ripe pumpkin was washed thoroughly and peeled. The pumpkin was cut into two halves and the seeds and stringy bits were removed. Then, the pumpkin was cut into small shreds. The cut shreds were dehydrated at 80°C temperature for about 8 hours using a drying oven. The dried shreds were ground using a grinder and sieved. Finally, pumpkin powder was packaged for further use.

D. Preparation of Cinnamon Powder-Incorporated Pumpkin Cookies

Sugar and Margarine were beaten until they had a creamy and smooth texture. After that, wheat flour, Pumpkin flour, Cinnamon powder, and baking powder were sieved and gradually added to the mixture. All the ingredients were mixed together, and the dough was sheeted on the cutting board using a rolling pin. The dough was cut by using a desired mold cutter and those were transferred into an oil coated aluminum tray. The oven was preheated at about 180°C for 10-20 minutes. The cut cookies were sent to the oven to bake for about 15 minutes. Finally, the baked cookies were kept cool for about 5-7 minutes, and they were packed using polypropylene (PP) packaging material.

E. Preparation of Cinnamon Bark Oil-Incorporated Pumpkin Cookies

Sugar and Margarine were beaten until they had a creamy and smooth texture. Cinnamon oil was added to the mixture and mixed well. After that, wheat flour, Pumpkin flour, and baking powder were sieved and gradually added to the mixture. All the ingredients were mixed, and the dough was sheeted on the cutting board using a rolling pin. The dough was cut using a desired mold cutter, and the pieces were transferred into an oil coated aluminum tray. The oven was preheated at about 180°C for 10-20 minutes. The cut cookies were sent to the oven to bake for about 15 minutes. Finally, the baked cookies were kept cool for about 5-7 minutes and were packed using polypropylene (PP) packaging material.

F. Sensory Evaluation of Cinnamon-Incorporated Pumpkin Cookies

Cookies were evaluated for the sensory attributes, which include colour, taste, odour, texture, appearance, and overall acceptability, using 30 untrained panelists and 7 points hedonic scale.

G. Physico-Chemical Analysis

- Weight, diameter, thickness, spread ratio, volume, density, baking loss, and colour were analyzed as physical properties.
- Moisture content was analyzed using moisture analyzer 3 (OHAUS MB 45)
- Water activity was determined using a water activity meter (LABTOUCH-AWS/N1609009) according to Lerici (1983) method at the 25°C temperature.
- PH was analyzed using a pH meter.
- Titratable acidity was determined according to the SLS 729:2010 method using 0.1% mol/dm3

  standard NaOH solution and Phenolphthalein indicator reagents.
- Ash content was determined using a muffle furnace according to the AOAC 2000 method.
- Fat content was determined using the Soxhlet apparatus according to the (AOAC, 2000) method. Petroleum ether was used as the reagent.
- The protein content was determined by the Kjeldahl method. (AOAC, 2000)

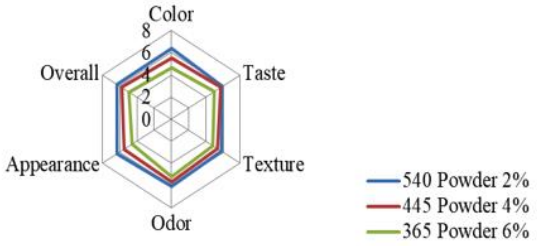

Fig. 1. Sensory evaluation radar chart of cinnamon powder-incorporated pumpkin cookies

H. Shelf-Life Determination

The cookies were packaged on polypropylene (PP) and were used for the shelf-life analysis during storage. The pH, moisture, water activity, colour, titratable acidity, yeast and mold count were analyzed within two weeks intervals for two months.

I. Microbial Analysis

According to SLS 516 book part 2 enumeration of yeast and mold count were enumerated.

J. Statistical Analysis

The data were analyzed by using one-way ANOVA, two-way ANOVA and SAS software. Sensory data were analyzed using one-way ANOVA. The mean separation was carried out by the least significant difference test and were compared at a 5% significant level ($P<0.05$).

III. Results

A. Sensory Evaluation

TABLE I. Sensory Evaluation Results of Cinnamon Powder Incorporated Pumpkin Cookies

Attribute	540 Powder 2%	445 Powder 4%	365 Powder 6%	Probability (α=0.05)
Color	6.4[a]	5.5[b]	4.6[c]	<.0001
Taste	5.9[a]	5.7[a]	5.0[b]	0.0036
Texture	5.8[a]	5.3[ab]	4.8[b]	0.0113
Odor	6.1[a]	5.7[ab]	5.2[b]	0.0136
Appearance	6.3[a]	5.5[b]	4.6[c]	<.0001
Overall	6.3[a]	5.8[b]	4.9[c]	<.0001

[a] The different letters mentioned in each value of the identical raw are significantly difference ($p<0.05$)

TABLE II. SENSORY EVALUATION RESULTS OF CINNAMON BARK OIL- INCORPORATED PUMPKIN COOKIES

Attribute	570 Oil 0.1%	455 Oil 0.3%	375 Oil 0.5%	Probability (α=0.05)
Color	6.1	6.0	5.6	0.1021
Taste	6.1[a]	5.5[a]	4.7[b]	0.0002
Texture	5.8	5.5	5.4	0.2807
Odor	6.1[a]	5.8[ab]	5.3[b]	0.0171
Appearance	6.1[a]	5.9[ab]	5.5[b]	0.0442
Overall	6.1[a]	5.9[ab]	5.5[b]	0.0007

[b.] The different letters mentioned in each value of the identical raw are significantly difference ($p<0.05$)

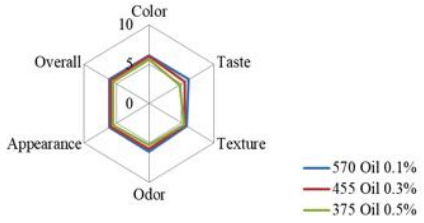

Fig. 2. Sensory evaluation radar chart of cinnamon bark oil-incorporated pumpkin cookies.

TABLE III. PHYSICOCHEMICAL PROPERTIES OF COOKIES

	Control	Powder 2%	Oil 0.1%	Probability	CV %
Moisture %	4.18	3.01	2.67	0.0742	20.50
pH	5.98[c]	6.01[b]	6.07[a]	<.0001	0.13
Water activity	0.24	0.28	0.26	0.097	8.11
Titratable acidity %	0.11[a]	0.09[b]	0.09[b]	0.0104	6.98
L* value	45.40[c]	47.10[a]	46.70[b]	<.0001	0.30
a* value	11.47[b]	11.50[b]	12.57[a]	0.0002	1.26
b* value	15.20[a]	13.53[c]	14.60[b]	<.0001	0.61
Protein %	3.14	3.19	3.27	0.3077	2.97
Fat %	30.91[a]	27.92[b]	26.88[b]	0.0119	3.99
Ash %	1.32	1.42	1.39	0.1362	3.67
Antioxidant activity %	35.57[b]	53.99[a]	36.09[b]	0.0008	8.01
Weight (g)	8.13	8.16	8.10	0.9929	6.74
Diameter (cm)	3.89	3.84	3.88	0.3312	0.95
Thickness (cm)	0.86	0.86	0.85	0.8382	1.82
Spread ratio	4.52	4.47	4.55	0.5666	1.96
Bake loss %	0.34	0.43	0.41	0.3662	18.08
Volume (cm^3)	10.20	9.96	10.07	0.5962	2.79
Density (g/cm^3)	0.80	0.82	0.80	0.8744	5.91

[c.]The different letters mentioned in each value of the identical raw are significantly difference ($p<0.05$)

According to Fig. 1, a cookie incorporated with 2% cinnamon powder obtained the highest score for all the sensory attributes. Figure.2 shows that the cookie incorporating 0.1% cinnamon bark oil obtained the highest score for all the sensory attributes.

B. Physico-Chemical Analysis

According to Tab. 3, There is a significant difference in pH, L* value and b* value among the three treatments. There is a significant difference in titratable acidity between the control and two treatments (oil and powder-incorporated cookies). There is a significant difference ($p<0.05$) in a* value between the oil and powder-incorporated cookies. Fat content is significantly different between control and two treatments (oil and powder-incorporated cookies). There is also a significant difference in antioxidant activity among the treatments. The highest antioxidant activity was detected in the cinnamon powder-incorporated pumpkin cookies. There was no significant difference in the physical properties among the three treatments.

IV. CONCLUSION

According to the sensory evaluation, 0.1% cinnamon bark oil and 2% cinnamon powder were selected as the best formulation for developing the product. It can be concluded that Cinnamon oil and powder can be used as natural flavoring agents in developing this cookie product.

According to the nutrition values, there was no significant difference in the protein and ash content among all three treatments.

The highest antioxidant activity was detected from the cinnamon powder incorporated pumpkin cookies.

According to the results of the shelf-life analysis, adding cinnamon has a positive effect on the shelf life, considering the growth of microbial, moisture, and water activity.

ACKNOWLEDGMENT

This research was financially supported by the National Cinnamon Research & Training Center, Matara, contract no. +94412245407.

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2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

Native Cyanobacteria from Sri Lankan Salt Marsh Ecosystem: A Promising Sustainable Solution to the Prevailing Food Crisis

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Abstract*—Hyperinflation, poverty, and environmental degradation lead to a sudden deterioration of the nutritional status in Sri Lanka. Crop-based food supply is more challenging due to rapid depletion of arable lands and limited availability of seasonal crops. Native cyanobacteria from extreme environments, specifically adapted with unique, richer nutrient profiles, could be promising alternatives for crop-based food production. Minimal growth requirements ensure their optimal growth in local environments and facilitate convenient utilization with minimal disturbance to the local biodiversity. In line with the above, 08 native cyanobacteria namely; *Leptolyngbya, Phormidium, Nostoc, Pseudanabaena, Nodosilinea*-I, *Limnothrix, Nodosilinea*-II, and *Oscillatoria* were isolated and morphologically characterized from salt marsh ecosystem in Mannar (8.9810° N, 79.9044° E), Sri Lanka, and nutrient analysis was carried out to identify their potential as promising natural alternatives to overcome food insecurity. Dry biomass of the strains was analyzed for total carbohydrate and protein contents using Dubois' method and Lowry method, respectively. Two strains showed more than 50% of total protein contents with the highest (58.0%) in *Pseudanabaena* sp. Three strains showed more than 40% of total carbohydrate contents with the highest (44.6%) in *Nodosilinea* sp.-II. Two more strains showed more than 25% of total carbohydrate contents. Results were promising and comparable with/higher than the contents found in general protein and carbohydrate food sources, highlighting their significant potential to be developed as macronutrient supplements. Rapid regeneration, easy access and availability throughout the year, make their utilization more promising over plant materials, as a sustainable approach to overcome food insecurity.

Keywords—Cyanobacteria, extreme environments, food insecurity, macronutrients

I. INTRODUCTION

Poverty, inequality, environmental degradation and climate changes have contributed towards a cumulative impact on the food supply, leading to a rapid deterioration of health and nutritional status of the people. Crop-based food supply is a challenge today, as number of arable lands are rapidly degrading with rapid, ever growing population. Many crops are seasonal with limited availability. Thus, the resulting food production is not sufficient to feed the whole population. It leads to nutritional inequality causing many health issues in different groups of the global population. According to the report on 'The state of the world's children 2019: Children, food and nutrition', malnutrition is more prevalent among children and adolescents from the poorest communities while the overweight in the child population is increasing at an alarming rate in rich countries. This creates a rapid deteriorating pattern of health and nutritional status in the world [1]. With the limitations of crop/plants-based food production, identifying a sustainable approach with other natural and safe alternatives is essential to ensure nutritional equity among communities. Photosynthetic cyanobacteria could be a better alternative for crop-based food production. Cyanobacteria species such as *Spirulina* spp. are rich with proteins contributing to more than 50% of its dry biomass while minerals are contributing to 2.2-4.8% of its dry biomass. Thus, *Spirulina* spp. have been identified as suitable nutritional supplements for vegetarians and are utilized as food and feed additives in food, pharmaceutical and cosmetics industries [2]. *Nostoc* sp. and *Anabaena* sp. have also been identified as nutrient rich sources and are utilized in Chile, Mexico, Peru and Philippines as human food [2]. However, cyanobacteria from extreme environments may have richer nutrient profiles compared to commonly found cyanobacteria as they could be uniquely adapted to ensure their survival in extreme environments. Identification of these potential native strains would be more important as they can be easily grown in local environmental conditions and can be utilized sustainably in industrial applications, without causing any threats to the local biodiversity. Therefore, this study was carried out to investigate and identify the potential of cyanobacteria from Sri Lankan extreme environments in providing a sustainable approach to address the prevailing food insecurity.

II. METHODOLOGY

A. Sample Collection, Preparation and Isolation

Water samples were collected from 06 sites of the salt marsh ecosystem in Mannar (8.9810° N, 79.9044° E), Sri Lanka. Samples were cultured in BG-11 medium under the fluorescent light with 2000 lux constant light intensity, in a shaking incubator at a 200-rpm shaking speed. After

cyanobacteria growth was observed, they were sub cultured onto agar plates containing the same BG-11 medium solidified with 1.5% (w/v) bacteriological agar [3], using the spread plate method. Frequent sub culturing was carried out using spread plate and streak plate culturing techniques and uni-algal cultures were obtained by transferring isolated colonies repeatedly to newly prepared plates. Then isolated uni-algal cultures were sub cultured in to liquid BG-11 medium in 100 ml and 250 ml conical flasks.

B. *Morphological Characterization of Purified Monocultures of Cyanobacteria*

Prepared slides were observed under the compound light microscope (Euromex Bioblue.lab bb. 1153-pli). Microscopic images were photographed using Image Focus 04 software. Morphological characteristics of the strains were carefully observed, studied, and compared with the morphological characteristics described by reference [4] for identification.

C. *Mass Culturing of Cyanobacteria*

Mass culturing of 08 morphologically characterized strains was carried out in sterile 50 L size fish tanks with one fifth strength of respective BG-11 at pH 7.5 along with aeration, under greenhouse environment with natural light and ambient temperature conditions. The biomass was harvested using filtration methods. The dried biomass was then ground to obtain a fine powder using a mortar and pestle and the powdered biomass was used for nutrient analysis.

D. *Nutrient Analysis*

Total carbohydrate content was analyzed using Dubois' method [5]. Twenty-five milligrams of dry cyanobacteria biomass were used for the analysis. The biomass was first hydrolyzed with 2.5 N HCl and the diluted, hydrolyzed extract was used for the analysis. The total carbohydrate content was calculated using the standard curve plotted with D-Glucose. The total protein content was analyzed using Lowry method [6]. Twenty milligrams of the dry biomass were used for the analysis. The final protein concentration was calculated using the standard curve established with bovine serum albumin dissolved in lysis buffer. Three replicates of the samples were used in each analysis. Data were statistically analyzed and compared using One-way ANOVA Tukey Pair-wise comparison (p=0.05) using Minitab 17 (2016) software version 2.0.

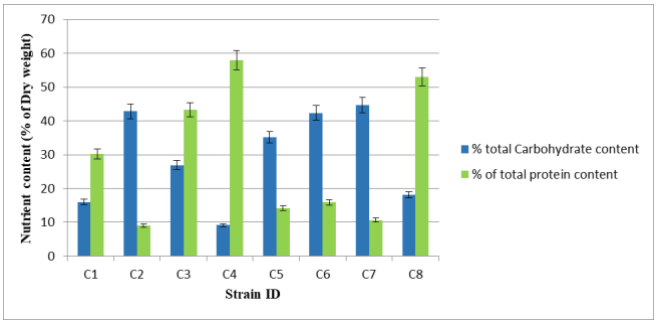

Fig. 1. Total carbohydrate and protein contents as a percentage of dry weight of biomass in eight cyanobacteria strains tested

III. Results

Based on the careful microscopic observations and comparisons carried out with the morphological characteristics described by reference [4], eight isolates were morphologically characterized as; C1-*Leptolyngbya* sp., C2-*Phormidium* sp., C3-*Nostoc* sp., C4-*Pseudanabaena* sp., C5-*Nodosilinea* sp.-I, C6-*Limnothrix* sp., C7-*Nodosilinea* sp.-II, and C8-*Oscillatoria* sp.

Pseudanabaena sp. (C4) and Oscillatoria sp. (C8) were recorded with the highest total protein contents of 58.0% and 53.0%, respectively (Fig. 1). Considerably higher total protein contents found in these strains were closer to the recorded average protein contents (63.0%) of Spirulina plantensis [7] which is widely used as a food source all over the world. Therefore, results highlight the potential of these native strains to be improved as protein supplements.

Moreover, Nostoc sp. (C3) was recorded with significant amounts of total protein (43.3%) and total carbohydrate (27.0%) contents (Fig.1). Nostoc is a well-known blue green alga which is appreciated as a healthy food and traditional medicine all around the world [8]. Specifically, Nostoc commune has been consumed in many countries in Asia and utilized as an ingredient in traditional medicine in China [8]. These strains were isolated and purified from salt marsh ecosystem where they are highly exposed to frequent dehydration and rehydration, osmotic stress, and radiation induced stresses. All these conditions could be favorable for these native strains to produce water stress proteins and it could be a possible reason for them to show remarkably higher protein contents compared to other species. Among tested strains, C7 which was morphologically characterized as Nodosilinea sp.-II was recorded with the highest total carbohydrate content of 44.6% while Phormidium sp. (C2) (42.8%) and Limnothrix sp. (C6) (42.4%) also showed more than 40% of total carbohydrate contents (Fig.1) and these contents were significantly higher than the carbohydrate contents (8%-28.4%) in many previously reported cyanobacteria [9]. As carbohydrate sources, cyanobacteria are more promising as they are also known to be easily digestible due to the absence of complex polysaccharides in their cell wall. Thus, the above graph shows promising results for many of the tested strains, highlighting their higher potential to be developed and utilized as nutrient supplements in nutrient-based applications. Cyanobacteria are naturally occurring botanicals and easily available in any environment. Most of them are fast growing, require less space and nutrients for the growth and they can be cultivated throughout the year. Native cyanobacteria growing in extreme ecosystems can uniquely modify themselves to adjust and survive under fluctuating environmental conditions therefore; they can be grown in any local environment, without causing any threats to the local biodiversity. Also, they can be regenerated in the same space. With all these advantageous characteristics and rich nutrient contents, these native strains from salt marshes could be identified as promising alternatives over plant material to ensure food security through an environmentally friendly, cost effective and sustainable approach.

IV. Conclusions

Native cyanobacteria strains such as *Pseudanabaena* sp. and *Oscillatoria* sp. with rich protein contents can be improved as protein supplements while *Nodosilinea* sp.-II, *Phormidium sp*. and *Limnothrix* sp. can be identified as easily digestible carbohydrate alternatives to be utilized in nutrient based applications. *Nostoc* sp. with considerable amounts of both proteins and carbohydrates can be improved as macronutrient supplements. However, an extensive molecular characterization is essential to confirm the identity of the strains. Their toxin producing capabilities also need to be analyzed as a future step of ensuring their safe consumption. Nutritionally rich strains which are safe for consumption can be further screened and they will be recommended for commercial applications in food industry such as developing them as macronutrient supplements, protein supplements or incorporating them in different food products. As these native strains from extreme salt marsh ecosystems are uniquely and well adapted to the local environments, they ensure convenient and sustainable utilization in nutrient-based applications without causing any threats to the local biodiversity.

Acknowledgment

Financial support provided by Access Engineering PLC, Sri Lanka is gratefully acknowledged.

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2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

Evaluation of Yield Advantage and Water Productivity of Maize-Groundnut Inter-Cropping Systems in the Dry Zone of Sri Lanka using Agricultural Production Systems sIMulator (APSIM)

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***Abstract*—The APSIM (Agriculture Productions Systems SImulator)–Maize & Groundnut model has been utilized on a global scale to assess the effects of various farming practices on the growth of maize and groundnut intercropping. However, limited attention has been given to modeling the crop productivity (t/ha) and water productivity (t/ha/m^3) of maize and groundnut intercropping under conditions such as rainfed or rainfed with supplementary irrigation, in tropical SouthAsia. To address this gap, we tailored and assessed the APSIM–Maize & Groundnut intercropping model for two widely cultivated Sri Lankan varieties: *Pacific* (Maize) and *Lanka Jumbo* (Groundnut). The APSIM model was introduced to simulate the growth, development, and yields of maize-groundnut intercropping in the Dry Zone of Sri Lanka, utilizing field experimental data. The model calibration process involved utilizing the first set of data to determine varietal parameters. The simulation results demonstrated a high level of agreement between the simulated values and the actual measurements during the growing periods as RMSE and RRMSE values for maize yield were 0.89 t/ha and 11.37% while that for groundnut was 0.108 t/ha and 7.7%. RMSE (Root Mean Square Error) quantifies the average prediction error in the same units as the target variable. RRMSE (Relative RMSE) normalizes RMSE by the range of observed values, providing a percentage-based measure for better comparison across datasets with different scales. The model accurately predicted grain yield for maize and groundnut under moisture-limited field conditions, showcasing a strong fit with the observed data. This fit was consistent across various factors, including cultivation year, season, time of planting (i.e., with rainfall or based on specific planting dates), variety, and water management practice (e.g., completely rainfed or rainfed with supplementary irrigation). Traditionally, many maize farmers grow this crop as a standalone crop. However, introducing groundnut as a secondary crop alongside maize offers advantages such as additional income and enhanced soil fertility. It was evident from the results that maize-groundnut intercropping can be used to get a high yield with a limited amount of water during periods of low rainfall such as the *yala* season and it is a very good solution to water scarcity. In situations where rainfall or other essential factors are delayed, employing crop modeling with APSIM becomes crucial to augment reliance on supplemental water resources and meet the specific requirements for maize and groundnut crops.**

Keywords—Maize, groundnut, intercropping Water productivity, APSIM, yield advantage

I. INTRODUCTION

APSIM is well-known for its capacity to model diverse facets of agricultural systems, encompassing crop growth and development, soil processes, water balance, nutrient cycling, and the effects of climate variability. By integrating these elements into a cohesive simulation framework, APSIM offers valuable insights into how various factors affect agricultural productivity and sustainability [1].

Maize (*Zea mays L.*), is a cereal crop globally, serving as a staple food, animal fodder, and a crucial raw material for diverse industrial applications [1]. Maize holds significant importance in Sri Lanka due to its versatile applications and economic contributions. As a staple crop, maize plays a vital role in the country's food security, providing a source of nutrition for the population. Additionally, maize cultivation supports the livelihoods of many farmers, strengthening the agricultural sector. Maize is a key ingredient in livestock feed

production, supporting the poultry and dairy industries. Moreover, the crop serves as a vital raw material for various industries, including food processing, starch production, and biofuel manufacturing. Its multifaceted role underscores its pivotal position in Sri Lanka's agriculture and economy.

Groundnut (*Arachis hypogaea L.*), commonly known as peanut, holds significant economic and nutritional importance in Sri Lanka as a vital oilseed crop. Tracing its origins back to South America, this leguminous plant has become a fundamental aspect of the country's agriculture, contributing to both subsistence and commercial farming. Groundnut is highly valued for its versatility, ranging from being a source of edible consumption to the extraction of high-quality oil, making it a crucial commodity in the domestic market and a potential contender in the global market.

Intercropping, the concurrent cultivation of two or more crops in close proximity, is a practice deeply ingrained in traditional agriculture worldwide. In Sri Lanka's agricultural landscape, primarily dominated by smallholder farmers, intercropping systems hold significant promise for enhancing productivity, ensuring food security, and promoting sustainable agricultural practices. Maize and groundnut intercropping has gained attention recently as a promising intercropping system, in the Dry Zone (DZ) of Sri Lanka.

Sri Lanka's DZ, known for its limited and unpredictable rainfall, poses unique challenges for agriculture. Within this region, optimizing water usage is crucial to ensure agricultural productivity and livelihood sustainability. Intercropping, a practice involving the simultaneous cultivation of two or more crops on the same piece of land, offers a potential solution Therefore, the aim of the study was to evaluate the performance of a locally adapted APSIM Maize - Groundnut model for simulating crop and water productivity of Maize-Groundnut intercropping system.

II. Methodology

A. Field Experiment

The field experiment was conducted from November 2022 to September 2023 in consecutive *Maha* and *Yala* seasons at Field Crop Research and Development Institute (FCRDI), Mahailuppallama. (8.0729° N, 80.8743° E) located in the DZ Mahailluppallama, Anuradhapura, Sri Lanka. The Experiment was designed as a Randomized Complete Block Design (RCBD) in triplicates. Maize variety *Pacific* and groundnut variety *Lanka Jambo* were used as crop varieties. Each block was comprised of a randomly assigned maize monocrop plot (spacing: 0.6 x 0.3 m), a groundnut monocrop (spacing: 0.45 x 0.15 m) plot, and a maize-groundnut intercropping plot (spacing maize; 0.45 x 0.3 m; spacing groundnut: 0.3 x 0.25 m). Each plot size was 12 x 4.05 m. All management practices were carried out according to the recommendations of the Department of Agriculture, Sri Lanka.

Crop phenology and growth data were collected as seedling emergence, number of days to reach 50% flowering, Leaf Area Index (LAI), and total above ground dry weights. Dry weights were measured using a one-square-meter sampling area at 50% flowering for both maize (silking) and groundnut and, during the harvest.

B. Modelling Experiment

The APSIM 7.10 version was used for the modelling exercise.

Input data: Climate data were collected from a local weather station in the Mahailluppallama study area from 2003 - 2023. Physical and chemical parameters of soil data gathered from laboratory analysis and as secondary data. The crop and management data were fed according to department recommendations, as they had been implemented in a field experiment.

Parametrization and validation: Model parameterization was done using the field experimental data and the validation was done by using the previous experimental data conducted by FCRDI in previous years and seasons. The performance of the model was evaluated by comparing simulated data such as crop yield and growth parameters with field measurements and also used a 1:1 graph for qualitative (graphical) validation and RMSE "(1)" value and RRMSE "(2)" value for quantitative (statistical) validation.

(1) $RMSE = \{\sqrt{\sum i=1n(Yi-Yi\hat{})2}\}/n$

(2) $RRMSE = RMSE/\max(Y)-\min(Y)$

Yield advantage and water productivity: The yield advantage was evaluated by calculating the Land Equivalent Ration (LER) and the water productivity was calculated as follows.

$$Water\ Productivity = \frac{Yiled\ (t/ha)}{water\ requirement\ (mm)}$$

Scenario Analysis: Scenario analysis for maize-groundnut intercropping was done using APSIM with 20 years of past weather data to evaluate the yield stability of the intercropping system across long-term climate variations.

III. Results

A. Yield Advantage of Maize-Groundnut Intercropping

According to the results, the Land Equivalent ratio (LER) calculated from experimental data for maize-groundnut intercropping was 1.74±0.2 indicating the yield advantage of the intercropping system. In validation, it was found that RMSE and RRMSE values for maize yield where was 0.89 t/ha and 11.37% while that for groundnut were 0.108 t/ha and 7.7% indicating good model performance [3].

Figure 1, 1:1 graph shows a visual representation of the fitness of simulated and observed yields. Data points of both maize and groundnut yields of the intercropping system were fitted well close to 1:1 line indicating the good fitness.

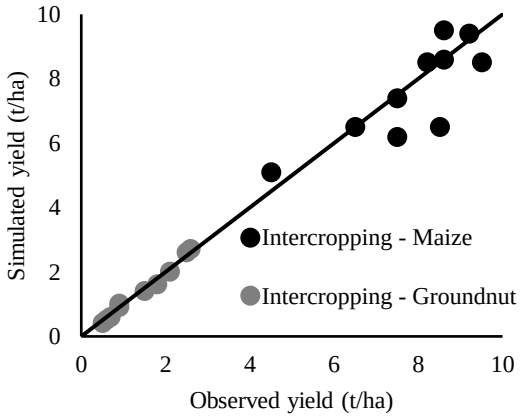

Fig. 1. Observed and Simulated Yield of Maize-Groundnut Intercropping in MI

B. Maximum Water Productivity

As shown in Figure 02, it was found that simulated and observed water productivities for monocrop and intercrop were in good agreement indicating APSIM model's capability of simulating water productivity in both monocropping and intercropping systems. The observed results indicated that Maize in intercropping system gave a higher water productivity than its monocropping.

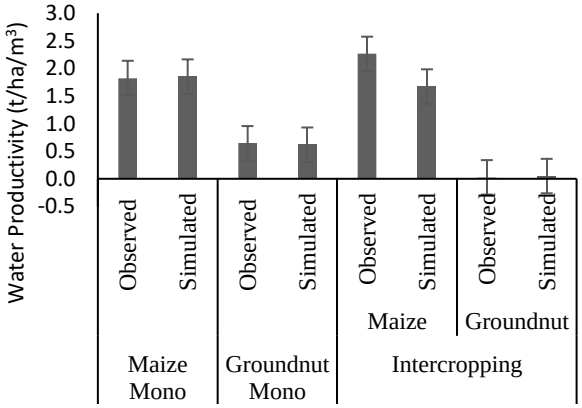

Fig. 2. Observed and Simulated Water Productivity of Maize Groundnut Monocropping and Intercropping in MI (2022/23 Maha Season)

IV. DISCUSSION

The aim of this study was to evaluate the performance of maize-groundnut intercropping system which was recently found as a promising system in the dry zone of Sri Lanka. Since the value of LER was 1.74±0.2, which was greater than 1 indicates a yield advantage. Therefore, this system can be effectively practiced by farmers in the dry zone of Sri Lanka. The dry zone region of Sri Lanka, particularly during the *yala* season, grapples with water scarcity, significantly impacting crop cultivation. In light of this challenge, employing an intercropping system emerges as a principal and highly effective solution. The study scrutinizes the maximum water productivity of crops, particularly focusing on maize and groundnut monocrops. Water requirements for maize monocrop and groundnut monocrop were observed at 1.8 t/ha/m^3 and 0.6 t/ha/m^3, respectively, representing the essential amount of water necessary for their optimal growth in a monoculture scenario. However, the study underscores that in the intercropping system, the total water requirement was reduced as ground nut showed a lower water requirement in the intercropping system. Accordingly, for maize, the water requirement was 2.2 t/ha/m^3, whereas for groundnut, it was a considerably lower 0.02t/ha/m^3. Thus, intercropping manifests as a prudent strategy that optimizes water use, showcasing considerable water-saving potential compared to conventional monocrop cultivation. APSIM simulation model, a sophisticated tool in the agricultural modeling. This model operates by simulating crop growth, water utilization, and resultant yields based on specific input parameters. The results of model validation confirmed specifically with the RRMSE values that APSIM model could simulate the yields of maize and groundnut cultivars used in the experiment with good accuracy [3]. Thus, simulated outcomes aligned proportionally with the observed data, thereby validating the accuracy and reliability of the APSIM model in predicting maize and groundnut crop yields within an intercropping. The presented details highlight the importance and the potential of maize-groundnut intercropping as a pivotal approach to address the water scarcity issues in the dry zone of Sri Lanka, showcasing how it significantly economizes water usage while augmenting crop yields. Moreover, the inclusion of advanced simulation tools like APSIM enriches the research, affirming the credibility of intercropping strategies through data-driven modeling and predictions.

V. CONCLUSION

This study shows the potential of intercropping, particularly maize-groundnut intercropping, as a sustainable approach to water conservation and enhanced agricultural productivity. When combined with the use of advanced simulation tools like APSIM and following expert recommendations for optimal management, intercropping becomes a promising solution to address water scarcity and achieve high agricultural yields in Sri Lanka and similar regions.

ACKNOWLEDGMENT

This research was financially supported by the Sri Lanka Tecnological Campus Responsive Research Grant contract no. RRSG.22.0811.3.

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2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

Environmental Aspect Assessment in a Poultry Meat Processing Facility Compliant with ISO 14001 Standards: A Case Study in Colombo District

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***Abstract*—This study aimed to identify the key environmental indicators responsible for making poultry meat production one of the most polluting food processing industries in Sri Lanka. For that, the environmental aspects of a large-scale meat processing plant were assessed using the guidelines of ISO 14001:2015 Environmental Management System (EMS) and conducting a risk assessment through an impact aspect register in terms of the severity of consequences and the likelihood of occurrence. The poultry meat production site demands a significant amount of energy and water, both valuable natural resources. As part of the production process, it generates livestock waste and wastewater. The impact of these environmental aspects is particularly pronounced in the processing unit, where pollution levels are at their highest significant environmental impact. To mitigate this impact, a vertical integration (Key stages in materials, suppliers, manufacturing, and distribution of supply chain ownership management business strategy) system was implemented to reduce waste generation and enhance resource utilization efficiency. This study aims to introduce new or refine existing indicators to propose solutions for mitigating the environmental impacts associated with poultry meat production plants.**

Keywords—Environmental impact, environmental aspect, environmental risk, environmental management system

I. INTRODUCTION

Chicken meat production is anticipated to reach 103.4 million metric tons in 2023, with Brazil and the US taking the lead. In 2021, global poultry production reached 70.7 billion, with China being the largest contributor. The US anticipates 1% growth, while Brazil is poised to achieve a 3% increase [1]. The poultry industry in Sri Lanka plays a vital role in ensuring food security. Despite a slight market contraction of -1.7% in 2022, despite increasing consumption, the sector faced challenges between 2020 and 2022 due to a decline in exports and an increase in imports from Thailand, Brazil, and the US [4]. Poultry production has a detrimental impact on the environment in several ways. This includes inadequate management of manure and litter, improper disposal of waste from processing plants (such as blood, bones, feathers, etc.), as well as issues related to bird carcasses, dust, insects, and unpleasant odors. Additionally, intensive poultry production is accountable for greenhouse gas emissions, acidification, and eutrophication. In a poultry processing industrial setting, environmental aspect assessment serves as a systematic method for identifying potential environmental impacts [2]. Environmental Aspect Assessments for livestock industrial sites are now managed using drone technology to enable real-time monitoring and life cycle assessments for measuring carbon footprints [3]. To evaluate these impacts, the use of the ISO 14001:2015 Environmental Management System Impact Aspect Register is vital to identify the environmental aspects associated with each practice [5]. This research emphasizes the need for a systematic framework customized for the poultry sector, sheds light on the insufficiency of existing environmental tools, and advocates for global sustainability and the reduction of environmental impacts [6]. This research aimed to provide an analysis of a large-scale poultry meat processing plant in the Colombo district Sri Lanka by leveraging the ISO 14001:2015 Environmental Management System (EMS) and conducting a risk assessment through an impact aspect register. Moreover, this study underscores the significance of assessing environmental risks in meat production facilities by utilizing a risk rating matrix [7] as a means to enhance existing operational conditions.

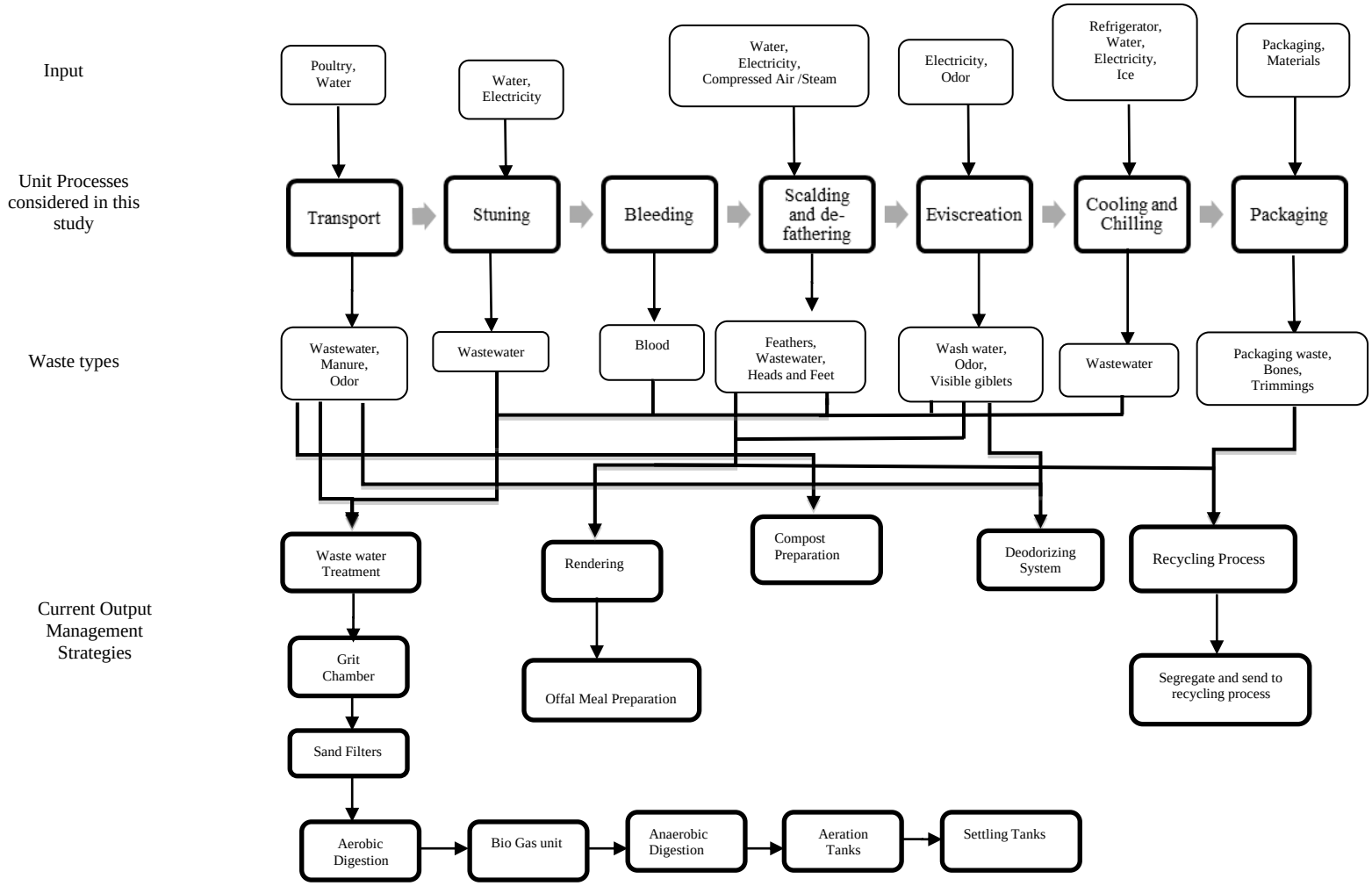

Fig. 1. Process flow diagram of the processing plant for the poultry meat processing facility of this study

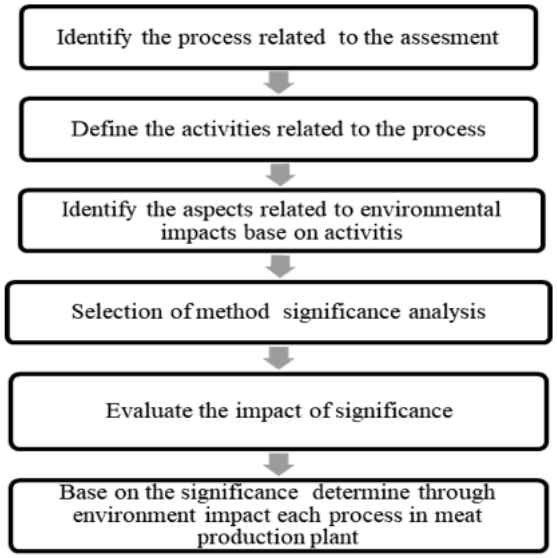

Fig. 2. Environment aspect assessment process [8]

A. *Environment Significant Rating Matrix*

Equation 1 [10] which was developed to assess the environmental aspects was used to determine the environmental significance rating [9]. The rating matrix, used for this study, is presented in Table 1. The degree of impact was established by analyzing the primary activities influencing the process, and this impact level was assessed using the scale outlined below [10]. The identification of critical aspects and the prioritization of these aspects were carried out through a systematic assessment.

Rs (Risk Significance) = Severity of consequences + Probability of occurrences + Scale and boundaries (1)

1. Low or slight damage to the environment
2. Medium damage is limited or has a medium impact on the environment
3. Significant damage to the environment

II. Materials And Methods

A. *Study Site*

This study was carried out at a large-scale poultry meat processing plant with a daily processing capacity of approximately 20,000 to 30,000 live birds. The selected site is situated in the Colombo District, Western Province of Sri Lanka. Figure 1 illustrates the process flow diagram of the processing plant. This diagram encompasses each specific unit process that was considered in this analysis.

B. *Environment Aspect Assessment*

The indicator ranking method was employed as part of the environmental aspect identification process from the poultry meat processing plant following the guidelines of the ISO 14001:2015 Environmental Management System. This approach is illustrated in Fig. 2 [8]. This study was conducted over a six-month period, from January 2023 to June 2023. It involved on-site visits to poultry meat processing plants and the collection of information through interviews with plant managers and supervisors. The gathered data was used to determine various aspects of meat processing operations.

Table 1: Significant Rating Matrix

Score	Severity of consequences	Probability of occurrence	Scale/ Boundaries
1	Unhealthy workplace and conditions on a short basis: minor controlled spills or very low	Rarely	Working areas (workshops or offices)
2	Slight health and safety impact on toxicity is that harmful materials leak into an enclosed environment /low	Annually	The departmental level is composed of many working areas.
3	Slight health and safety impact on human health or medium	Monthly	Inside the plant facility
4	Acute health and safety effects cause permanent disabilities. A hazardous substance spill or leak requires internal intervention and is high-risk.	Weekly	Inside the plant facilities (Adjacent areas)
5	Fatality of extreme environmental effects is very high.	Daily	Outside the organization's site or city area

The significance of an environmental aspect was determined by the sum of scores (K) for all levels of the aspect, according to equation 1 [10]. The overall significance score of the environmental aspect was derived based on the guidelines provided in Tab. 2 [10]. Consequently, this allowed for the determination of the impact levels associated with each unit operation within the processing plant.

Table 2: Overall Significance Score of Environment Aspect

Index	Name	K (sig) value	Additional condition
I	Insignificant	3 - 7	No significant
S	Significant	8 -15	Significant level

II. Results and Discussion

The management team at the processing plant is actively striving to enhance resource efficiency and environmental management. These efforts contribute to the development of a resource-circular economy. According to the current analysis of the significance and insignificance of each production and processing plant (Tab. 3), the following processes had the most significant environmental impact. The processing plant, along with the cool room and blast freezers, exerts the most significant environmental impact. According to the data presented in Figure 01, the processes in question result in the generation of various types of waste, including wastewater, feathers, manure, blood, heads and feet, visible giblets, packaging materials, and bones. Currently, conventional practices, as depicted in Figure 01 involve treating wastewater/washed water through biological treatment methods, aerobic and anaerobic digestion methods, and physical treatment methods, grit chamber/sand filters/aeration tanks, and settling tanks are part of wastewater management. Additionally, an odor reduction system is employed to mitigate the generation of unpleasant odors. The management of manure involves composting it within a designated composting plant process. Fixed dome biogas plant is linked with anaerobic digestion process in wastewater treatment plant as shown in Figure 1. Eviscerated materials, gut waste, and feathers are utilized in the rendering process to create offal meals. Furthermore, packaging materials are separated and forwarded to the recycling process. Solid waste was a streamlined stage of slaughter that involved removing the offal and solid waste (gut waste) and other disposal by-products or raw materials. Wastewater generation was identified as another point with specific mandatory cleaning and disinfection practices. Wastewater processing, inventory, and storage are needed for purification or treatment, and wastewater release is shown on the inland water surface as purified before discharged into agricultural lands are all examples of necessary cleaning. Manure traps and grease traps are used to clean and disinfect infected drains. Energy management system used to assess and implement energy-saving options. The environmental risk corrective action plan and standard operating procedures are implemented based on ISO 14001. Boiler units, steam generators, cool rooms, and blast freezers are other processes that have an impact on the environment due to intensive electricity usage and thermal energy waste generation. Enhancements were made to the wastewater treatment process by introducing a bio-chemical treatment method to regulate biochemical oxygen demand and chemical oxygen demand levels. The reduction of wastewater and waste generation was achieved through the implementation of standard operating procedures, as well as the enhancement of worker effectiveness through training programs as part of a comprehensive strategy. Additionally, biological waste generation was minimized by utilizing feed-rendering. An integrated approach involved the utilization of wastewater for agricultural purposes. Furthermore, an EMS was employed, which included the development of an operation control action plan to enhance system management.

TABLE 3: STATUS OF SIGNIFICANT RATING

Process	Significant Rate	Insignificant Rate
Garage/Maintenance point	4	4
Fuel Pumping Point	0	4
Transport	5	2
Tube well	1	4
Processing	7	2
Cool Room and Blast freezer	7	3
Generator	2	5
Broiler and steam generator	6	3
Microbiology Lab	3	4
Packing Material Printing Room	1	3
Loading Point	0	6
General Stores	1	5
Solid waste Collecting Plant	2	2
Offal Room	3	3
Rendering Plant	4	6
Wastewater Treatment Plant	6	3
Sludge Collection Room	1	5
Compost Preparation Plant	2	2

III. Conclusion

The established research examined the direct and indirect effects of a poultry meat processing facility, providing a systematic evaluation and presenting a roadmap for risk reduction and the implementation of sustainable practices. The optimal solution involves fostering sustainability within the poultry industry by embracing resource-efficient practices, strengthening environmental regulations, and educating consumers to mitigate the industry's negative environmental impacts. This research not only underscores the significance of a structured approach in evaluating environmental aspects but also serves as a foundational guide for making sustainable decisions and formulating effective mitigation strategies in industrial operations.

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2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

Substituting Gelatin with Stabilizer Derived from Fiddleheads of *Acrostichum aureum* (Karan koku) in Set Yoghurt

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Abstract*—Stabilizers play a prominent role in improving the texture of yoghurt and preventing undesirable whey separation. Moreover, stabilizers rich in hydrophilic colloids possess the capability to bind water, increase viscosity, and ultimately enhance the overall quality of yoghurt. This research investigated the potential of utilizing plant-derived stabilizers, specifically the extract from *Acrostichum aureum,* known as Karan Koku (KK) as a promising substitute for gelatin in the production of set yoghurt. The experimental design was developed with four treatments: a control group using 0.6% gelatin, and three experimental groups using 0.4%, 0.6%, and 0.8% Karan Koku fiddlehead extracts. Sensory properties were analyzed for yoghurt samples containing KK fiddlehead extract at these three concentrations and the best treatment group was selected. The chosen treatment group, along with the control group of yoghurt made with 0.6% gelatin underwent and investigation of their physicochemical and microbiological properties. Yoghurt prepared with 0.6% KK exhibited the most favorable sensory attributes compared to the others. While a decrease in pH was observed in KK added yoghurt during storage, it remained within the acceptable pH range in yoghurt. The titratable acidity was notably higher in KK added yoghurt in first two weeks. Additionally, there was a significant increase in syneresis in the KK added yoghurt over the storage period. Streptococcus thermophilus showed significantly higher levels in KK added yoghurt. KK fiddlehead extract, at a concentration of 0.6% can be used as stabilizer without having much detrimental effects on quality attributes, however further studies are required to reduce the syneresis.

Keywords—Substitutes, gelatin, stabilization, Acrostichum aureum, yoghurt

I. INTRODUCTION

Stabilizers are essential ingredients in yoghurt production which involves in improving the texture, consistency, and shelf life of yoghurts. Common stabilizers used in yoghurt production include gelatin, pectin, agar, carrageenan, and guar gum. These stabilizers help prevent issues such as syneresis (whey separation) and maintain the desired thickness of yoghurt. Gelatin is widely used but poses challenges for vegans, vegetarians, and those with dietary restrictions, leading to the exploration of alternative stabilizers [1]. *Acrostichum aureum*, also known as Karan koku, is a fern species that has gained attention as a potential natural stabilizer in yoghurt production. Its properties make it a promising alternative to gelatin. This fern offers stabilizing attributes, binding water, and increasing the thickness of yoghurt [1].

Unique combination of its stabilizing properties and additional nutritional benefits would be beneficial in using it as a major ingredient in yoghurt manufacturing. Apart from its stabilizing power, KK possesses antibacterial, antimicrobial, and antioxidant properties. These added health benefits can enhance the overall appeal of yoghurt, making it an attractive choice for both producers and health-conscious consumers [1].

The main objective of this study was to investigate the effect of KK extract as a stabilizer on physicochemical, sensory, and microbiological properties of set yoghurt.

II. METHODOLOGY

A. Preparation of Acrostichum aureum Fiddlehead Extract

KK fiddleheads were collected from the Low Country Wet Zone in Sri Lanka. Fiddleheads were thoroughly cleaned, cut into pieces, blended, and squeezed to form a gel with filtering. The collected gel was stored at 4°C after extraction.

B. Experimental Design

The experiment was designed with four experimental groups and three replicates per treatment. Set yoghurt prepared with 0.6% of gelatin and 0% of fiddlehead gel was used as the control group whereas the treatment groups of yoghurts were prepared with 0.4%, 0.6%, and 0.8% of KK fiddlehead extracts [2].

C. Sensory Evaluation

Sensory evaluation was carried out using 30 semi-trained panelists to select the best concentration of fiddlehead mucilage using 9-point hedonic scale to select the best concentration of KK fiddlehead extract to be incorporated into set yoghurt. Appearance, color, odor, taste, texture, and mouth feel of the yoghurt samples were evaluated.

D. *Analysis of Physicochemical Properties*

After selecting the best treatment group out of the three concentrations of KK fiddlehead extracts, the selected treatment group was further analyzed along with the yoghurt of control group.

E. *pH Value and Titratable Acidity*

The pH, and titratable acidity of the yoghurts were measured according to the method described in AOAC, (2005). The yoghurt sample dissolved in distilled water and mixed well. The amount of 1 ml of Phenolphthalein indicator will be introduced into 10 ml of the mixed solution. It was then titrated against 0.1 N Sodium Hydroxide solution until pink color emerged for complete neutralization.

Calculations

$$TTA\% = \frac{(N \times V \times \text{Molecular weight of lactic acid}) \times 100\%}{\text{Weight of the sample}}$$

Where;

TTA=Total titratable acidity

N = Normality of NaOH

V = Volume of NaOH

F. *Determination of Syneresis*

Syneresis of the yoghurt samples was measured using undisturbed yoghurt samples (without mechanical disturbances) during cold storage at 4°C. The syneresis measurement was carried out using a 25ml measuring cylinder by draining out the expelled whey carefully [3].

G. *Viability of Fermentative Bacteria in Yoghurts*

The viability of Lactobacillus bulgaricus and Streptococcus thermophilus bacteria in yoghurts was measured as described by Almusallam et al. [4] to assess the effect of functional ingredients on the fermentation process.

III. Results and Discussion

This study focused on evaluating the potential of KK as a plant-derived stabilizer to replace gelatin in set yoghurt.

The sensory assessment findings (Figure 1), clearly highlighted a significant variation in certain sensory attributes when 0.6% KK was introduced into the yoghurt. This observation held great importance, prompting the choice of 0.6% KK for subsequent analysis.

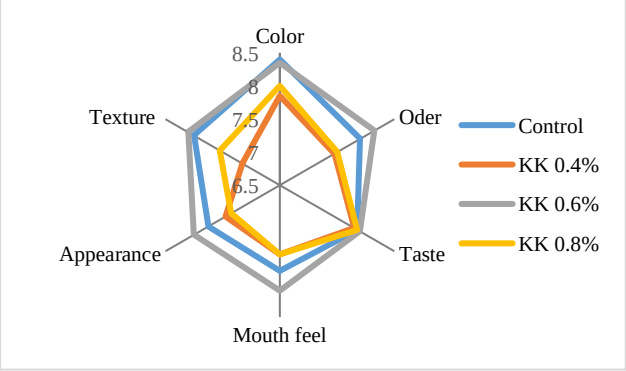

Fig. 1. Sensory evaluation results of set yoghurt incorporated with KK

As indicated in Table 1, the pH values of both the control and treatment groups did not exhibit any significant differences, except on Day 14. Although the pH value showed a decline during the storage period in the yoghurt with KK addition, all the samples consistently maintained their pH within the range of 4.0 to 4.6. This consistency suggests that the product quality remained stable and stayed within the crucial acidity range required for yoghurt, ensuring its quality and safety [5].

Table 2 revealed increase in titratable acidity of the yoghurt samples over the storage period despite the addition of KK. This finding demonstrates that the acidity of the yoghurt remained on an upward trend during storage, which can be attributed to various factors such as microbial activity and fermentation [6]. Minimum titratable acidity level of 0.15% had been established as a quality criterion for yoghurt [7] while all the samples in this study exceeded this predetermined threshold. This means that even with the incorporation of KK the acidity levels in the yoghurt remained well above the minimum requirement for yoghurt quality.

Information on syneresis provides valuable insights into the water-holding capacity and stability of the yoghurt during the storage period. Syneresis refers to the separation of whey or liquid from the yoghurt's gel-like structure. In this study, the addition of KK. resulted in a significant increase in stabilizing property.

The study involved monitoring the growth of two essential yoghurt cultures, L. bulgaricus and S. thermophilus over a 21 days' storage period (Table 4, Table 5). It was observed that the growth of these critical yoghurt cultures did not exhibit any decline until Day 14. This suggests that both L. bulgaricus and S. thermophilus maintained their populations reasonably well during the initial two weeks of storage. The presence of KK led to a decrease in the count of L. bulgaricus on Day 1 and Day 21 compared to the control group, indicating a reduction in the population of this specific bacteria. In contrast, the addition of KK had a different effect on S. thermophilus, as it contributed to an increase in its growth.

This finding is significant as it suggests that the addition of 0.6% KK did not negatively impact the viability of these essential bacteria. The viability of these cultures is crucial for yoghurt fermentation and quality because they are responsible for the fermentation process [6].

TABLE 1. CHANGE OF PH VALUES (MEAN±STANDARD DEVIATION) IN SET YOGHURT INCORPORATED WITH KK

Treatment	Day 0	Day 7	Day 14	Day 21
Control (0.6% gelatin)	4.32±0.01	4.25±0.01	4.23 ± 0.01^{a}	4.18±0.01
KK (0.6% fiddlehead gel)	4.32 ± 0.01^{A}	4.26 ± 0.01^{B}	4.20 ± 0.01^{bC}	4.18 ± 0.01^{D}

[a, b] Differing superscripts within columns indicate means that were significantly different (P<0.05).

[A, D] Differing superscripts within row indicate means that were significantly different (P<0.05).

TABLE 2. CHANGE OF TITRATABLE ACIDITY (MEAN±STANDARD DEVIATION) IN SET YOGHURT INCORPORATED WITH KK

Treatments	Day 0	Day 7	Day 14	Day 21
Control (0.6%) gelatin)	0.56 ± 0.01^{bC}	0.58 ± 0.01^{bC}	0.63 ± 0.01^{B}	0.73 ± 0.01^{A}
KK (0.6% fiddlehead gel)	0.60 ± 0.01^{aC}	0.63 ± 0.01^{Ab}	0.63 ± 0.05^{B}	0.71 ± 0.01^{A}

[a, b] Differing superscripts within columns indicate means that were significantly different (P<0.05).

[A, C] Differing superscripts within row indicate means that were significantly different (P<0.05).

TABLE 3. SYNERESIS (%) (MEAN±STANDARD DEVIATION) IN SET YOGHURT INCORPORATED WITH KK

Treatment	Day 0	Day 7	Day 14	Day 21
Control (0.6% gelatin)	32.78 ± 0.74^{bC}	32.52 ± 0.35^{bC}	37.43 ± 0.43^{bB}	38.92 ± 0.15^{bA}
KK (0.6% fiddlehead gel)	42.93 ± 0.53^{aB}	42.24 ± 0.84^{aC}	42.13 ± 0.29^{aC}	46.36 ± 0.15^{aA}

[a, b] Differing superscripts within columns indicate means that were significantly different (P<0.05).

[A, C] Differing superscripts within row indicate means that were significantly different (P<0.05).

TABLE 4. *LACTOBACILLUS BULGARICUS* GROWTH (LOG CFU/G) IN SET YOGHURT INCORPORATED WITH KK

Treatment	Day 0	Day 7	Day 14	Day 21
Control (0.6% gelatin)	7.96 ± 0.15^{aC}	9.40 ± 0.10^{B}	9.86 ± 0.25^{B}	11.86 ± 0.32^{aA}
KK (0.6%				
fiddlehead gel)	3.66 ± 0.15^{bC}	9.53 ± 0.25^{A}	9.63 ± 0.30^{A}	8.06 ± 0.30^{bB}

[a, b] Differing superscripts within columns indicate means that were significantly different (P<0.05).

[A, C] Differing superscripts within row indicate means that were significantly different (P<0.05).

TABLE 5. *STREPTOCOCCUS THERMOPHILUS* GROWTH (LOG CFU/G) IN SET YOGHURT INCORPORATED WITH KK

Treatment	Day 0	Day 7	Day 14	Day 21
Control (0.6% gelatin)	4.23 ± 0.15^{bC}	7.13 ± 0.15^{aAB}	7.50 ± 0.10^{bA}	6.66 ± 0.41^{bB}
KK (0.6% fiddlehead gel)	5.33 ± 0.21^{aD}	6.56 ± 0.25^{bC}	11.33 ± 0.07^{aA}	9.73 ± 0.45^{aB}

[a, b] Differing superscripts within columns indicate means that were significantly different (P<0.05)

[A, D] Differing superscripts within row indicate means that were significantly different (P<0.05).

IV. CONCLUSION

The findings from the current study support the replacement of gelatin with selected plant-derived stabilizers, which is with 0.6% KK fiddlehead extract. Results indicated that addition of KK at 0.6% concentration did not have any adverse effects on pH and titratable acidity values. Furthermore, findings of this study demonstrated that the addition of KK specifically at a concentration of 0.6% had a positive effect on S. thermophilus, ultimately supporting the overall quality of yoghurt production. By observing the increase in syneresis due to KK addition, this research highlights a potential challenge that needs to be addressed to ensure the product's stability and consumer appeal. It may prompt further investigations into optimizing the formulation or processing conditions to mitigate this issue while still harnessing the benefits of KK as a stabilizer.

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2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

Quantifying Carbon Footprints within Higher Education Institutions: A Case Study of Sri Lanka Technological Campus

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***Abstract*—In response to the imperative of reducing greenhouse gas emissions, organizations are progressively taking steps to quantify their carbon footprint. The purpose of this paper is to present a comprehensive analysis of the carbon footprint of Sri Lanka Technological Campus, including direct and indirect emissions as well as a discussion about the commonly used method. Emissions are presented in two scopes (scope 1 reports direct process emissions, scope 2 reports emissions from purchased energy) to identify carbon emission hotspots within the university's operations. Direct sources and indirect sources of greenhouse gas emissions in the university are identified and relevant activity data are collected. The carbon footprint of the University was calculated using collected activity data followed by the hybrid model, combining approaches of Environmentally Extended Input-Output Analysis and Life-Cycle Assessment. In 2022, the institution's emissions inventory tallies to 196.89 metric tons of CO_2e, with the majority attributed to the indirect emissions of the campus. Approximately 72% of the University's carbon footprint is attributed to indirect emissions. This underscores the imperative for adopting environmentally conscious procurement practices and transitioning to renewable energy sources for purchased electricity as a means of offsetting this impact. The study revealed that significant impediments are associated with information availability for cover up all categories and the absence of established data collection strategies. Effective mitigation actions involve the adoption of energy conservation policies and enhancements to procurement practices to reduce carbon footprint of the university.**

Keywords—Carbon footprint, higher education institutes, greenhouse gas emissions, indirect emission

I. INTRODUCTION

Climate change concerns have led to an increased focus on evaluating emissions and quantifying a carbon footprint. This has become particularly significant as a first step toward minimizing one's environmental impact and ultimately reaching carbon neutrality. Currently, there is a considerable gap between the capacity of natural carbon sinks to capture carbon and the global emissions being discharged [1]. Reduction of greenhouse gas (GHG) emissions identified as one of the most crucial steps in mitigating climate change. Therefore, numerous organizations, institutions, countries, and other groups in the national and international levels are actively involving to reduce emissions and achieve carbon neutrality. As higher education institutes for learning and research, universities also have the potential to make advancements independently, separate from national regulations or mandatory requirements [2]. Adopting innovative technologies and methods supported by their research, while raising a sense of sustainability and climate-friendly in younger generations, represent feasible approaches. Universities making official pledges toward achieving carbon neutrality would be help in conveying the message to other entities, including governments, demonstrating a hands-on action in the battle against climate change [3]. The quantification of carbon footprints, which measure greenhouse gas emissions, offers higher education institutes to establish a starting point when targeting forcarbon neutrality.

The carbon footprint evaluates all greenhouse gas emissions resulting from and associated to the activities of a system. This involves emissions originating directly from the system, along with specific indirect emissions caused by the selected system boundaries [4]. Besides carbon dioxide, methane, nitrous oxides, and fluorocarbons (HFC and PFC) are the main other greenhouse gases that are included. To address this, emission inventories mainly use the term 'CO2 equivalents' (CO2e). The result of such an assessment can assist in identifying the primary emission sources, serving as a baseline for designing efficient strategies to reduce greenhouse gas emissions [IPCC, 2014]. At the organizational level, it's essential to pay special consideration to standards like the GHG Protocol Corporate Standard [5]or ISO 14064-1 [6] when quantifying the carbon footprint. Usually emissions are assigned to scopes and categories in carbon footprint calculation. Guidelines of GHG Protocol Corporate Standard anticipated the division of the released greenhouse gases into three scopes. The first category represents to emissions directly caused, such as those resulting from on-site fossil fuel combustion. Scopes 2 and 3incorporate the indirect emissions]. Scope 1 and 2 only reflects energy-related, indirect emissions, which are resulting from the generation of the energy procured by the institution. Scope 3 includes all other non-energy-relatedindirect emissions, which incorporate emissions from activities like business travel and waste management [2].

Higher education institutions are insisted to set objectivesto become carbon neutral sooner in order to set an example for future generations of learners. The carbon footprint can act as a crucial instrument, not just for identifying the major sources of emissions but also for increasing awareness among both staff and the student community. Generally usedapproach for determining a university's carbon footprint is a

hybrid model that combines two distinct methods for evaluating environmental effects: Life-Cycle Assessment (LCA) and Environmentally Extended Input-Output Analysis (EEIOA). Using this approach, emissions from scope 1 and 2 would primarily be calculated using activity data and suitable Emission Factors [EFs], whereas categories related to procurement and acquired equipment would depend on financial records and relevant EFs, particularly [2].

Universities, which are frequently swarming with varied people and energy-intensive businesses, have a big impact on local and global carbon footprints. In case of this, our study aimed to clarify Sri Lanka Technological Campus carbon footprint as well as the complex procedure involved in estimating and measuring emissions in accordance with Scope 1 and Scope 2 categories to the calendar year 2022. As the significance of this study has increased because of concerns about climate change and a worldwide dedication to reducing greenhouse gas emissions, having a thorough and precise understanding of carbon emissions on the campus is essential. The results of this study will not only benefit for Sri Lanka Technological Campus but will also serve as a reference for other institutions motivated to reduce their carbon footprint and engage in responsible environmental stewardship.

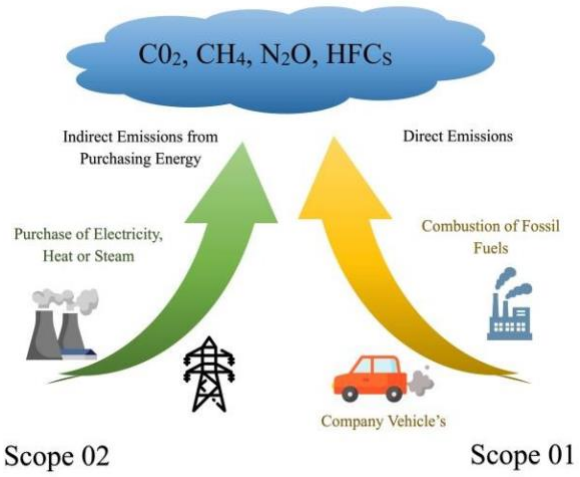

Fig. 1. Scopes of emissions of the university used for the study

II. MATERIAL AND METHODS

A. Sri Lanka Technological Campus

Sri Lanka Technological Campus (SLTC) is situated in western province of Sri Lanka and had around 4000 registered students plus about 300 staff members in 2022. Two main campuses are situated in the western province, splitting the city campus at the TRACE Expert city in Colombo and main campus at the Padukka premises. This study focused main campus which is located at Padukka spanning an area of 46.3 Acres. The university offers study programs on many levels, for example the university has five faculties: technology, engineering, computing and IT, science and music.

Fig. 2. Map of the study area. The mark indicates the Sri Lanka Technological Campus

B. Calculation Approach

The calculation of the University carbon footprint followed by the Greenhouse Gas Protocol Corporate Standard [5], Data related to the consumption of energy and the up keeping of the properties were mainly calculated and provided by the University's facility management. Information needed for the remaining emission categories was gathered by the university's carbon footprint research group. The carbon footprint will be presented in tonnes of CO_2 equivalents, following the global warming potential reported by the IPCC, 2014 [1] for all greenhouse gases (GHG). The choice of measuring emissions in accordance with scope 1 and 2 categories for the calculation of carbon footprint is influenced by the data availability of the university.Obtaining quantified solid waste data for the year 2022 within the university posed a significant challenge.

C. Scope 1: Direct Emissions

All emissions (E_{GHG}) assigned to scope 1 were determined using a life-cycle assessment (LCA) method, involving the multiplication of activity data (AD_{S1}) by the suitable emission factors (EFs). The calculation employed the following formula:

$$E_{GHG} = AD_{S1} \times EF \quad (1)$$

The activity data for direct emissions referred here incorporates information gathered from greenhouse gas emissions that originate directly from sources within the university premises. Direct emission sources were identified by conducting a physical survey and walk through assessment within the university. Suitable EF is chosen through IPCC (2014) and Greenhouse Gas Protocol Corporate Standard. Following table shows the direct emission sources within the university as identified in this study.

TABLE I. DIRECT SOURCE EMISSIONS WITHIN THE UNIVERSITY

Direct Emission Sources	Type
Diesel Generator	Point
Liquefied Petroleum Gas	Point
Grass Cutter	Point
Air Conditioners	Non point - Fugitive
Fire Extinguishers	Non point - Fugitive

D. *Scope 2: Indirect, energy related emissions*

Scope 2 includes the indirect emissions (E_{GHG}) resulting from the utilization of purchased electricity. The primary method employed for the calculation involves multiplying consumption data (CD_{S2}) by suitable emission factors, which also take into consideration the local conditions. The following equation was used for the calculation:

$$E_{GHG} = CD_{S2} \times EF \quad (1)$$

Consumption data for indirect emissions within the university is acquired from the facility management of the campus to the year 2022. Appropriate EF is chosen through Sustainable Energy Authority of Sri Lanka.

III. RESULTS AND DISCUSSION

The total amount of emissions associated with the Sri Lanka Technological Campus sums up to 196.89 t CO_2e for the year 2022. To enhance comparability with other universities, the carbon footprint can also be expressed as 0.04 tons of CO_2 equivalent per person, considering the total number of students and staff members (4800). Fig. 3 shows the visualization of the carbon footprint and Table 2 displays the results in greater detail.

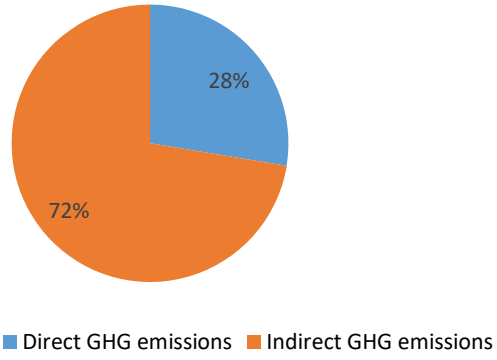

Fig. 3. The carbon footprint of SLTC in 2022

Based on the findings, scope 2 indirect emissions contribute significantly more to the university's carbon footprint, making up 72% of the total. This indicates that the electricity purchased for the campus contributes more to greenhouse gas emissions in the atmosphere than emissions from direct sources. Also, electricity sourced from renewable energy is considered carbon-neutral, it's important to not overlook energy efficiency and conservation in the future. This is because the carbon footprint is not the single sustainability metric that a higher education institution should take into account. Therefore, the university's carbon footprint can be reduced by implementing renewable energy sources for electricity procurement or generation. With regard to renewable electricity, the SLTC could further extend the deployment of solar photovoltaic (PV) systems on the roofs of its main campus areas to contribute to the broader energy transition.

TABLE 2. CARBON FOOTPRINT ESTIMATION IN SLTC

	EMISSIONS - SLTC Padukka Premises		Function of the campus	CO2-e TOTAL (Tonnes p.a)	Carbon (CO_2)	Methane (CH_4)	Nitrous (N_2O)
	Scope 01 - Direct GHG emissions and removals in tonnes CO2-e			**54.32**	**39.39**	**0.44**	**0.06**
1	Direct emissions from Stationary Combustion	Generator	Teaching and learning	19.75	19.69	0.02	0.04
	Direct emissions from Stationary Combustion	LPG	Other	13.89	13.88	0.01	0.01
	Direct emissions from Stationary Combustion	Grass cutter	Other	6.13	5.70	0.41	0.01
	Direct fugitive emissions from the release of GHGs in anthropogenic systems.	AC	Teaching and learning	14.43	-	-	-
	Direct fugitive emissions from the release of GHGs in anthropogenic systems.	Fire Extinguishers	Safety	0.12	0.12	-	-
2	**Indirect emissions in tonnes CO2-e - Category 2**			**142.57**			
	Scope 02 - Indirect GHG emissions from imported energy			**142.57**			
	Indirect emissions from imported electricity		Teaching and learning	142.57			
	TOTAL EMISSIONS SCOPE 1 and 2			**196.89**			

Furthermore, new procurement policies should be introduced at the university, favouring more energy-efficient or sustainable products within the bounds of economic feasibility. For instance, the campus can purchase inverter air conditioning systems, which can lead to a decrease in direct fugitive emissions. The University of Jyvaskyl in Finland¨ reported a carbon footprint of 40,873 t CO_2e in 2019 [7] and University of Olu, Finland reported carbon footprint as 19,072 t CO_2e in 2019 [2]. These universities in Europe are characterized by their substantial size, with approximately 20,000 students and a greater demand for electricity, especially during the winter heating season. Also, due to the presence of numerous components, laboratories, and facilities, these universities exhibit a higher carbon footprint compared to the one observed at this campus. These universities included scope 3 emissions in their carbon footprint calculations, whereas the current study exclusively concentrated on scope 1 and 2 emissions. Consequently, the current findings indicate a somewhat lower value. While the significance of higher education institutions striving for carbon neutrality is widely acknowledged today, it's equally important to closely examine the methods and strategies through which a university should attain this goal. Offsetting, compensation measures, or merely procuring renewable energy are straightforward and quickly implementable actions, but they may not result in enduring carbon neutrality in the long run [2]. Scope 3 indirect non-energy-related emissions encompass staff members' business travel, fuel consumption for rented vehicles, procurement activities, and waste management data. These data play a substantial role in determining the university's ultimate carbon footprint. Therefore, it is important to quantify carbon footprint by accounting all 3 scope emissions. Despite the global trend among higher education institutions toward sustainability, SLTC has not yet developed a sustainability or carbon-neutral plan for the university. This study emphasizes the importance of embracing carbon neutrality as a responsible higher education institution in Sri Lanka. Additionally, the measured carbon footprint presented in this study can inform decision-making processes related to adopting sustainable alternatives and green procurement etc.

This calculation of the carbon footprint provides an appropriate starting point for the university to start considering the reduction of environmental impacts by its operations. Based on this, university can implement sustainable policies such as energy saving policies, and kind of mitigation measures can be adopted. affiliations as succinct as possible. As stated before, scope 2 emissions significantly contribute more to this study. If only purchased electricity produced by renewable energy sources the institution’s carbon footprint could be reduced by over 142.57 t CO2e, lowering the share of Scope 2. Depending on the chosen categories, the results of educational organizations can vary greatly. Recognizing the substantial influence of indirect, non-energy related emissions on the carbon footprint is crucial, and there should be a strong endorsement for the compulsory incorporation of the principal categories within this scope. Recognizing the Offsetting is generally not a significant factor in the calculation of a higher education institution's (HEI) carbon footprint. Offsetting is typically viewed as a potential option following the carbon footprint calculation and is mainly contingent on the outcomes of that calculation. Furthermore, one could contemplate how to factor in the beneficial influence of a university's research when assessing environmental and sustainability objectives. So it is acceptable to employ methods like the carbon footprint to quantify the possible reductions in emissions facilitated by research and education. The findings of this study emphasize the necessity for the university to validate sustainable strategies as part of its commitment to a more sustainable future, aligning itself as a responsible higher education institution.

IV. Conclusion

Carbon footprint of Sri Lanka Technological Campus for the year 2022 was quantified and results indicate a total of 196.89 tons of CO_2e emissions under scope 1 and scope 2 emissions. Notably, a significant portion of this figure, approximately 72%, is attributed to the purchased electricity, a finding that deviates from the patterns observed in other documented case studies. This underscores the importance of tailoring mitigation measures to the unique local characteristics of the higher education institution (HEI). Adopting for purchasing renewable energy would be considerably reduce the carbon footprint of the campus. Therefore, authors see a need for better-investigated input data and more specific emission factors to use scope 3 emissions and include ultimate carbon footprint quantification of the study. It will enhance the comprehensiveness and accuracy of this study. Therefore, this case study can serve as educational resources in this context, and by comparing the methods employed, best practices can be developed.

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2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

Use of *Terminalia arjuna* (Kumbuk) Leaves as a Plant-derived Stabilizer to Replace Gelatin in Set Yoghurt

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***Abstract*—Stabilizers in yoghurt enhance texture and prevent whey separation in yoghurts. Gelatin is commonly used as the primary stabilizer in yoghurt. For various health and ethical reasons, consumers might opt to refrain from gelatin, often driven by concerns related to animal welfare and treatment. In this study, plant-derived stabilizers, particularly *Terminalia arjuna* (Kumbuk) leaf extract, was explored as an alternative to gelatin in set yoghurt. *Terminalia arjuna* offers additional nutritional benefits such as antibacterial, antimicrobial, and antioxidant properties while possessing stabilizing power. This study investigated the physicochemical, microbiological, and sensory characteristics of set yoghurt incorporated with kumbuk leaf extract. The experimental design followed a completely randomized design (CRD) with four treatments: a control group using 0.6% gelatin, and three experimental groups using 0.4%, 0.6%, and 0.8% kumbuk leaves extracts. Set yoghurts were assessed for pH, titratable acidity, syneresis, and sensory evaluation, and viability of fermentative bacteria (Streptococcus thermophiles and Lactobacillus bulgaricus) over 21 days at refrigerated storage.**

***Keywords*—Substitutes, gelatin, stabilization, Terminalia arjuna, yoghurt**

I. Introduction

Yoghurt, a widely consumed fermented dairy product known for its health benefits and nutritional value, is currently one of the fastest-growing segments in the global dairy industry. Yoghurt's stabilizing properties encompass attributes like enhancement characteristics, gel-forming qualities, emulsification properties, pH adjustment capabilities, and even potential medicinal properties [1]. Gelatin, a primary stabilizer in yoghurt, serves the dual roles of binding water and increasing viscosity. The desire to find substitutes for gelatin arises from a range of factors, such as adhering to vegan and vegetarian diets, respecting cultural or religious dietary constraints, and managing allergies and sensitivities [1]. Substitutes commonly used in yoghurt to replace gelatin include agar-agar, pectin, tapioca starch, or carrageenan. These alternatives can substitute gelatin's thickening and gelling properties while omitting animal-derived ingredients, allowing yoghurt producers to accommodate a broader spectrum of consumer preferences and dietary requirements.

Terminalia arjuna leaves possess gelling and thickening characteristics due to the presence of certain natural compounds such as hydrolysable tannins. These tannins have the ability to interact with proteins and form complexes that contribute the gel-like structure in food and pharmaceutical applications [2].

The objective of this study is to determine the applicability of kumbuk leaf extract as a natural stabilizer in set yoghurt without compromising the quality attributes.

II. Methodology

A. Preparation of Kumbuk Leaf Extract

Kumbuk leaves were collected from the Low Country Wet Zone in Sri Lanka. Leaves were thoroughly cleaned, cut into pieces, blended, and squeezed to form a gel with filtering. The collected gel was stored at 4°C after extraction.

B. Experimental Design

The experimental design was a complete randomized design (CRD) with four treatments and three replicates per treatment. Set yoghurt mixture including 0.6% of gelatin and 0%of leaf gel was used as the control group whereas the

treatment groups of yoghurts were prepared with 0.4%, 0.6%, and 0.8% of kumbuk leaf extracts.

C. Sensory Evaluation

Sensory evaluation was carried out using 30 untrained panelists to select the best concentration of leaf mucilage using 9-point hedonic scale to select the best concentration of kumbuk leaf extract to be incorporated into set yoghurt. Appearance, color, odor, taste, texture, and mouth feel of the yoghurt samples were evaluated

D. Analysis of Physicochemical Properties

After selecting the best treatment group out of the three concentrations of kumbuk leaf extracts, the selected treatment group was further analyzed along with the yoghurt of the control group.

E. pH Value and Titratable Acidity

The pH, and titratable acidity of the yoghurts were measured according to the method described in AOAC, (2005). The yoghurt sample dissolved in distilled water and mixed well. The amount of 1 ml of Phenolphthalein indicator will be introduced into 10 ml of the mixed solution. It will be then titrated against 0.1 N Sodium Hydroxide solution until a pink color emerges for complete neutralization.

Calculations

$$\text{TTA \%} = \frac{(\text{N} \times \text{V} \times \text{Molecular weight of lactic acid}) \times 100\%}{\text{Weight of the sample}}$$

Where;

TTA %= Total titratable acidity

N = Normality of NaOH

V = Volume of NaOH

F. Determination of Syneresis

Syneresis of the yoghurt samples was measured using undisturbed yoghurt samples (without mechanical disturbances) during cold storage at 4°C. The syneresis measurement was carried out using a 25-ml measuring cylinder by draining out the expelled whey carefully [3].

G. Viability of Fermentative Bacteria in Yoghurts

The viability of Lactobacillus bulgaricus and Streptococcus thermophiles bacteria in yoghurts was measured as described by Almusallam et al. [4]. In order to assess the effect of functional ingredients on the fermentation process.

III. RESULTS AND DISCUSSION

This study focused on evaluating the potential of kumbuk as a plant-derived stabilizer to replace gelatin in set yoghurt and employed a multifaceted approach, incorporating sensory evaluation, physicochemical analysis, and microbiological assessment to determine the optimal concentration of kumbuk in yoghurt production.

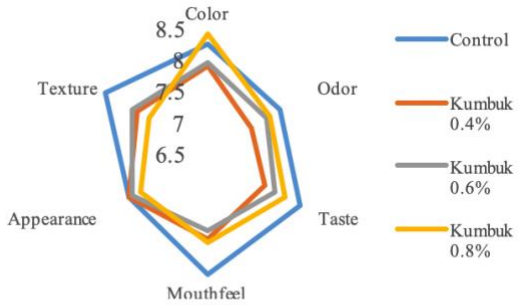

Fig. 1. Sensory evaluation of yoghurt incorporated with Terminalia arjuna (Kumbuk) leaves.

Significantly, the inclusion of 0.6% kumbuk in the yogurt led to a distinct variation in its texture, setting it apart from other yogurt samples containing different levels of kumbuk. Consequently, the yogurt group incorporated with 0.6% kumbuk was chosen for more extensive analysis. According to the Tab. 1. Over the storage period of yoghurt samples, their pH levels decreased in control samples. However, the kumbuk extract incorporated yoghurt sample exhibited some fluctuations during the storage period. In contrast, titratable acidity (Tab. 2.) increased progressively throughout the storage duration. The pH decreases and acidity increase is attributed to the high metabolic activity of lactic acid bacteria in the yoghurt [5]. Furthermore, adding kumbuk at 0.6% concentration increased syneresis (Tab. 3), which was observed to rise in both the control and treatment groups as the storage period continued. Similar findings have been observed in previous investigations [6], and have been linked to milk acidification, which causes a decrease in the charges on caseins, weakening the electrostatic forces that keep micelles together and lower steric stability. This reduces the attractive force between micelles, which become 'adhesive' or sticky and form a weak particle gel with serum separation [7]. Incorporating kumbuk leaf extract at a concentration of 0.6% reduced L. bulgaricus (Tab. 4) counts throughout the storage period. Further, while the yoghurts of the control group exhibited an increase in L. bulgaricus growth over the storage period, the treatment group indicated a decline in L. bulgaricus counts. These might be due to the available compounds in the yoghurt medium and produced compounds to the medium during the storage period [8]. The introduction of kumbuk at a 0.6% concentration had a contrasting effect on the growth of S. thermophiles (Tab. 5). The counts of S. thermophiles increased notably on Day 14 and Day 21 in the treatment group, demonstrating a growth enhancement during these specific time points, and this growth trend continued over the course of the storage period.

TABLE 1. PH VALUES (MEAN±STANDARD DEVIATION) OF YOGHURT INCORPORATED WITH KUMBUK LEAF EXTRACT

Treatment	*Day 1*	*Day 7*	*Day 14*	*Day 21*
Control (0.6% gelatin)	4.32 ± 0.01^{bA}	4.25 ± 0.01^{bB}	4.23 ± 0.01^{aC}	4.18 ± 0.01^{D}
Kumbuk (0.6% leaf gel)	4.36 ± 0.01^{aB}	4.40 ± 0.01^{aA}	4.17 ± 0.01^{bC}	4.18 ± 0.01^{C}

[a-b] Mean values in the same column with different superscripts differ significantly ($p<0.05$)
[A-D] Mean values in the same row with different superscripts differ significantly ($p<0.05$)

TABLE 2. TITRATABLE ACIDITY (MEAN±STANDARD DEVIATION) OF YOGHURT INCORPORATED WITH KUMBUK LEAF EXTRACT

Treatments	*Day 1*	*Day 7*	*Day 14*	*Day 21*
Control (0.6% gelatin)	0.56 ± 0.01^{C}	0.58 ± 0.01^{bC}	0.63 ± 0.01^{bB}	0.73 ± 0.01^{A}
Kumbuk (0.6% leaf gel)	0.55 ± 0.01^{D}	0.64 ± 0.01^{aC}	0.72 ± 0.01^{aA}	0.71 ± 0.01^{B}

[a, b] Mean values in the same column with different superscripts differ significantly ($p<0.05$)
[A-D] Mean values in the same row with different superscripts differ significantly ($p<0.05$)

TABLE 3. SYNERESIS (MEAN±STANDARD DEVIATION) VALUES OF YOGHURT INCORPORATED WITH KUMBUK LEAF EXTRACT

Treatment	*Day 1*	*Day 7*	*Day 14*	*Day 21*
Control (0.6% gelatin)	32.78 ± 0.74^{bC}	32.52 ± 0.35^{bC}	37.43 ± 0.43^{bB}	38.92 ± 0.15^{bA}
Kumbuk (0.6% leaf gel)	35.87±0.49aD	37.23±0.66aC	42.43±0.80aB	44.25±0.35aA

[a, b] Mean values in the same column with different superscripts differ significantly ($p<0.05$)
[A-D] Mean values in the same row with different superscripts differ significantly ($p<0.05$)

TABLE 4. VIABILITY OF L.BULGARICUS (MEAN±STANDARD DEVIATION) IN YOGHURT INCORPORATED WITH KUMBUK LEAF EXTRACT

Treatment	*Day 1*	*Day 7*	*Day 14*	*Day 21*
Control (0.6% gelatin)	7.96 ± 0.15^{aC}	9.40 ± 0.10^{aB}	9.86 ± 0.25^{aB}	11.86 ± 0.32^{aA}
Kumbuk (0.6% leaf gel)	5.30 ± 0.20^{bB}	6.63 ± 0.20^{bA}	4.66 ± 0.20^{bC}	1.22 ± 0.05^{bD}

[a-b] Mean values in the same column with different superscripts differ significantly ($p<0.05$)
[A-D] Mean values in the same row with different superscripts differ significantly ($p<0.05$)

TABLE 5. VIABILITY OF S.THERMOPHILES (MEAN±STANDARD DEVIATION) IN YOGHURT INCORPORATED WITH KUMBUK LEAF EXTRACT

Treatment	**Day 1**	**Day 7**	**Day 14**	**Day 21**
Control (0.6% gelatin)	4.23 ± 0.15^{C}	7.13 ± 0.15^{aAB}	7.50 ± 0.10^{aA}	6.66 ± 0.41^{bB}
Kumbuk (0.6% leaf gel)	4.66 ± 0.20^{C}	6.10 ± 0.11^{bB}	7.26 ± 0.15^{aA}	7.70 ± 0.20^{aA}

[a-b] Mean values in the same column with different superscripts differ significantly ($p<0.05$)
[A-D] Mean values in the same row with different superscripts differ significantly ($p<0.05$)

IV. CONCLUSION

This study exhibited, the replacing of gelatin with *Terminalia arjuna* (kumbuk) leaf extract at the concentration of 0.6%. The results showed that replacing gelatin with kumbuk leaf extract accomplished positive results on the pH, acidity, and syneresis. The replacement of gelatin with 0.6% kumbuk leaf extract also showed positive impact directly on the pH, acidity, and some microbiological qualities. However, the effect on the S. thermophiles while indicating some antimicrobial action on L.bulgaricus. Furthermore, kumbuk leaf extract incorporation caused some higher syneresis and showed some drawbacks during this work. This should be addressed and investigated in near future works to confirm the suitability of plant-derived stabilizers for replacing the gelatin.

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2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

Sensory Attributes of Dried Chicken Jerky Incorporated with Purple Yam Powder

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***Abstract*—Consumer demand for protein-rich, convenient snack products, especially dried meats like jerky, has surged in recent years due to dietary recommendations favoring high protein and low carbohydrate intake. Chicken jerky, in particular, has gained popularity, offering a leaner and healthier alternative to traditional beef or pork jerky. Thermal processing during chicken jerky production may result in undesirable sensory attributes. This study has explored the use of purple yam powder to mitigate the undesirable changes of sensory attributes of chicken jerky. This study assessed the impact of incorporating dried purple yam powder at different concentrations (4%, 6%, and 8%) on the sensory characteristics of dried chicken jerky. Sensory evaluation was performed using the 9-point Hedonic Scale. Dried chicken jerky prepared with 6% and 8% purple yam powder exhibited no significant differences in color, flavor, tenderness, juiciness, and overall acceptability compared to those of the control group. Overall acceptability and the flavor attributes of chicken jerky incorporated with 4% purple yam powder were significantly higher (7.85±0.26) than those of the control group. These findings suggest that the addition of purple yam powder can enhance certain sensory attributes of dried chicken jerky, with an optimal concentration of 4%. This study offers valuable insights into enhancing the quality of chicken jerky while meeting the increasing consumer demand for healthier and visually appealing snack options.**

Keywords—Chicken jerky, purple yam, natural colorant, thermal processing, sensory evaluation

I. INTRODUCTION

The rising consumer interest in dried meat snacks, fueled by dietary recommendations for higher protein intake and lower carbohydrate consumption, has led to a diverse array of prepared meat snacks in the market, especially notable in Western nations. These meat snacks, including high-nutrient meat sticks, cater to the needs of active individuals and athletes, offering convenient on -the - go options [1]. Jerky, a popular, long-lasting snack made from lean meat strips, is widely consumed globally and is produced from various meats, such as beef, pork, turkey, and chicken [2]. Chicken jerky has gained popularity for its lean profile and is now commonly found in restaurants and food trucks worldwide. Jerky is favored for its nutritional benefits, including high protein content, low fat, antioxidants, vitamins, and minerals [1]. Chicken jerky, in particular, is often lower in fat and calories than other jerky varieties, making it an attractive choice for those seeking a healthier diet [3]. Sous Vide (SV) cooking has emerged as a unique method for preserving food quality, with extensive research conducted over the past 20 years covering food safety, storage duration, quality enhancement, nutritional impact, and various technical aspects [4] [5]. SV differs from conventional cooking in that it involves vacuum- sealed cooking at precise temperature and time parameters. This method not only reduces the risk of bacterial contamination but also inhibits the growth of anaerobic bacteria during food storage, allowing for longer shelf life and rapid post-cooking cooling. Furthermore, SV cooking preserves the flavor of food by minimizing oxidation, volatile ingredient loss, and moisture reduction [5]. SV cooking is versatile, applicable to a range of foods, including meats, poultry, fish, vegetables, and even desserts. Despite the advantages of SV cooking, a challenge in chicken jerky production is the development of undesirable dark colors during thermal processing, which can be attributed to the Maillard reaction, a chemical reaction between amino acids and reducing sugars [6]. This heat-induced reaction produces compounds that affect food color, flavor, and aroma through various stages. Factors like sugar and amino acid type, cooking temperature, food pH, and other compounds influence the rate and intensity of the Maillard reaction.

To address the issue of dark color development in chicken jerky during thermal processing, the use of natural color extracts has emerged as a viable solution. Natural colorants derived from edible sources, such as beetroot powder, paprika, and tomato powder, are considered safe for consumption, free from synthetic additives and artificial colors that may have potential health concerns [7] [8]. By incorporating natural colorants into jerky production, meat products can enhance their visual appeal, prevent discoloration issues, and maintain freshness and quality by providing vibrant and appealing colors, meeting the demands of health-conscious consumers. Moreover, the appeal of natural colorants aligns with consumers' perception of health, which is driving the demand for meat products with these ingredients. Additionally, the incorporation of purple yam,

rich in carbohydrates, proteins, fats, fiber, vitamins, minerals, and antioxidants, offers antioxidant benefits, particularly from anthocyanin compounds.

These anthocyanin and other phytochemical including polyphenols, carotenoids, dioscorins, phenolic acids indicated by purple coloring, possess strong antioxidant activity and can combat free radicals, potentially offering various health benefits, including anti-aging, anticancer, blood sugar regulation, and antihypertensive effects [9].

II. Methodology

A. Location of the Research

The experiment was conducted in the Food Science Laboratory of Sri Lanka Technological Campus (SLTC Research University), Padukka, Sri Lanka.

B. Experimental Design

TABLE 1. EXPERIMENTAL DESIGN FOR THE MARINADE

Ingredients of Marinade per 50 g of Chicken Slice	**Experimental Group**			
	Control	***T1***	***T2***	***T3***
Purple Yam Extract	-	4%	6%	8%
Salt	-	1%	1%	1%
Sugar	-	3%	3%	3%

C. Preparation of Purple Yam Powder

Purple yam was purchased from a local market in Western Province Sri Lanka. The purple yam was thoroughly washed with portable water, peeled, and then cut into thin slices. Purple yam slices were dipped in 1 % citric acid for 10 mins and blanched at 60℃ for 5 mins. Purple yam slices were dried in a hot air-dry oven at 55°C for 2 hours. Then dried yam was crushed with a grinder and sieved with a 100 - mesh.

D. Preparation of Yam Extract

Purple yam flour weighed as 4%,6% and 8% according to the Table 1. Each weighed purple yam flour samples were mixed with 50 ml hot water (60°C) and kept for 16 minutes to dissolve anthocyanin pigments [10]. Then extracts were filtered using a cheesecloth.

E. Preparation of a Chicken Jerky Snack

Boneless chicken breasts were purchased from a local Supermarket in Western Province, Sri Lanka. Chicken breasts were washed and cut into 50g weighed, 5 mm thin slices in equal-weight sections.

Marinade was prepared according to the Table 1. Meat slices were mix with marinade by hand marination for 3 min and marinated for overnight at refrigerated temperature (4°C). Marinated chicken jerky samples were dried at 70℃ for 4 hours using a hot air oven.

F. Sensory Evaluation

Sensory evaluation was conducted at Food Science Laboratory of SLTC Research University, Padukka with an untrained sensory panel consisting of 30 panelists. A ballot papers were given to the untrained panelist. Sensory evaluation was done for color, juiciness, flavor, tenderness and overall acceptability acceptance using a 9-point hedonic scale (ranging from 1 =Dislike extremely and 9 = Like extremely). It was done according to ISO 11136:2014 standard (11). Sensory Evaluation was performed on a white background tray and each panelist was given fresh light warm water to rinse their mouth.

III. Results and Discussion

TABLE 2. RESULTS OF THE SENSORY EVALUATION

Sensory Attribute	***Control***	***T1***	***T2***	***T3***
Color	8.85 ± 0.10^{A}	8.90 ± 0.10^{A}	8.90 ± 0.10^{A}	8.70 ± 0.17^{A}
Juiciness	6.05 ± 0.32^{A}	6.65 ± 0.39^{A}	5.70 ± 0.32^{A}	5.60 ± 0.19^{A}
Flavor	5.80 ± 0.37^{B}	7.50 ± 0.22^{A}	6.85 ± 0.24^{AB}	6.55 ± 0.27^{AB}
Tenderness	5.80 ± 0.33^{A}	6.70 ± 0.40^{A}	6.65 ± 0.25^{A}	6.45 ± 0.25^{A}
Overall acceptability	6.70 ± 0.24^{B}	7.85 ± 0.26^{A}	7.10 ± 0.25^{AB}	6.65 ± 0.31^{B}

$^{A-B}$ Mean values in the same row with different superscripts differ significantly ($p<0.05$)

According to the results (Table 2), there were no significant differences in color between the control group jerky and the jerky prepared with purple yam powder. T1 (Purple Yam Extract 4%) jerky experimental group received the highest preference for Juiciness, Flavor, Tenderness ($p<0.05$). Color attribute of T1 was not significantly different from the color preference ratings of T2 (Purple Yam Extract 6%) experimental group. T1 had the best overall acceptability compare to control group and other experimental groups the highest flavor score, enhancing the jerky's taste. As the purple yam powder content increased, the flavor, juiciness and tenderness gradually decreased. When high concentrated marinated meat exposed to drying it concentrate the yam extract compounds by removing excessive amount of juiciness. Tenderness also could be affected by this. This could lead to receive dry, brittle texture with low chewiness in jerky samples. This might be the reason for gradual decrement of sensory results as the purple yam powder content increased. T1 experimental group have well balanced level of yam extract which leads to balance all sensory attributes. Therefore, the addition of 4% purple yam powder to dried chicken jerky enhances its flavor without significantly affecting other sensory attributes, making it a promising option for product improvement.

IV. Conclusion

The study investigated the impact of adding different concentrations of purple yam powder to dried chicken jerky. The sensory evaluations revealed that the jerky with 4% purple yam powder had the highest overall acceptability score. This sample showed significantly higher flavor while

no significant differences in color, tenderness, and juiciness compared to the control group. However, as the concentration of purple yam powder increased to 8%, the overall acceptability scores decreased. Therefore, 4% concentration of purple yam powder appears to be the optimal choice for enhancing the quality attributes of dried chicken jerky.

ACKNOWLEDGMENT

The author would like to thank Department of Agricultural Technology at Sri Lanka Technological Campus and Department of Biosystems Technology, Faculty of Technology, University of Sri Jayewardenepura for providing the necessary support and resources to conduct this research.

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2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

Development of an Environmentally Friendly Energy Efficient Biofiltration System for Brackish Water Desalination

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***Abstract*—Desalination has garnered significant interest as a means of addressing the demand for freshwater; nonetheless, traditional desalination methods can prove expensive and have adverse environmental effects. Hence, this study aimed to design and develop a 'brackish water desalination system, that integrates marine algae and a biofilter liner system composed of mature compost, clay-polyethylene-clay composites. To begin, marine algae samples were gathered from Negombo, "Thalpe" beach, and Baticoloa lagoon and cultivated in a controlled laboratory environment. A well-developed sample was then chosen for the treatment system. Next, a portable trapezoidal pit-shaped model was constructed, measuring 90 cm across the top square, 30 cm across the bottom square, and with a depth of 30 cm. This structure was encased with steel wire mesh, with the bottom layer of mesh serving to release the water. The biofilter system was constructed with a 20-cm clay polythene-clay composite liner along with a mature compost layer. Algae have shown great potential in desalination processes due to their unique biological properties. The incorporation of algae-abundant Negombo Lagoon water in the final layer of the biofilter system serves a crucial role in desalinating the water. Characterization of brackish water of Negombo lagoon electrical conductivity, salinity ‰, total dissolved solids and pH was 17,910mS/cm, 35%, and 8,957ppm, 7.76 respectively. Hydraulic conductivity of the liner was 2.64×10^{-7} cm/sec. Parameters were taken from both filtrate and inside the bioreactor regularly at 4.00pm. The collaborative efforts of mature compost, algae, and the microalgal community proved successful in achieving a 90% reduction in salinity.**

Keyword—Brackish water, desalination, water scarcity, algae, biofilter

I. INTRODUCTION

Water scarcity is an ever-growing global challenge, intensified by the increase in population, urbanization, and industrial expansion. These factors contribute to the unsustainable exploitation and mismanagement of freshwater resources[1]. In this context, the demand for freshwater sources has driven widespread adoption of desalination as a feasible method for generating potable water. Nonetheless, conventional desalination techniques are frequently cost-prohibitive and may carry environmental risks [2]. Therefore, it is crucial to explore low-cost and sustainable desalination techniques.

Clay-polyethylene-clay composite liner system developed by the University of Peradeniya which is a live biofilter as a bottom liner of a reactor to make the system biological[3, 4]. The importance of vertical movement through dissimilar surfaces provides ideal conditions for both mineralization and conversion of ammonia to nitrate. The mineralized compounds are formed within the narrow passages and above the liner as solid phase reactions [3, 4]. On the other hand, compost is rich in beneficial microorganisms that can help break down and metabolize organic matter in the water. These microorganisms play a key role in the biological filtration process, as they can remove contaminants and help in the breakdown of organic material in the water[3][4][5]. Algae are characterized as a group of plants that lack roots, stems, and leaves, but they do contain chlorophyll [6]. Moreover, algae can be classified into a diverse range of organisms, varying in size from microscopic species smaller than certain bacteria to seaweeds that can reach lengths of several feet. Various types of algae thrive in different aquatic environments, be it in saltwater or freshwater, and under diverse climatic conditions throughout the year, where they can synthesize their components and food through photosynthesis. Algae, as a group, demonstrate an exceptionally broad tolerance for salt levels in their surroundings [6]. Algae can effectively reduce salinity levels in water through a process known as bioremediation. Algae can absorb and accumulate salt ions, such as sodium and chloride from the surrounding water.

As a result, this research project was initiated with the main goal of designing and developing a 'brackish water biofilter' system that incorporates algae, mature compost, and a clay-polyethylene-clay liner. This innovative system seeks to reduce salinity levels in brackish water, providing a

sustainable and cost-effective solution to the increasing water scarcity challenges experienced by coastal cities in Sri Lanka.

II. Methodology

The laboratory plant was located on the rooftop of the Research building, Sri Lanka Technological Campus (SLTC), Paddukka Premises, it was operated under natural conditions including average temperature (25 ºC – 27ºC), sunlight duration (12 hrs), and humidity (86%). The experiment was divided into four stages: a) Macro algae and microalgae sampling, b) algae growth experiments, c) performance assessment of the compost layer, and the d) laboratory-scale setup implementation and evaluation. Initially, the algae growth experiment took place at the Environmental Technology Laboratory of Sri Lanka Technological Campus, while the performance testing of the compost layer was conducted in Negombo (7°12'14.67"N, 79°51'11.51"E) an area with convenient access to the lagoon. The laboratory analysis was done at Environmental Technology laboratory and Civil Engineering Laboratory, Sri Lanka Technological Campus. In the pursuit of a comprehensive study on algae diversity and nutrient dynamics, four distinct locations within Sri Lanka were strategically selected: Negombo Lagoon, "Morawala" in Negombo, Batticaloa Lagoon, and "Thalpe" Beach in Galle, each representing urbanized, high-nutrient-rich environments[3][4]. As for the first step, further growing experiments for selected algae samples were conducted at the Environmental Technology Laboratory, Sri Lanka Technological Campus. The required waste polythene was collected from the university canteen and the required clay was collected from the paddy field located inside the university. Before introducing the algae to the setup hydraulic conductivity[5] test for the clay-polythene-clay liner was conducted with saline water and evaluated the performances at the Department of the Environmental Technology, SLTC. And the laboratory scale biofilter based desalination system was established and its performances were assessed.

A. Macroalgae and MicroAlgae Sampling

The sampling location may significantly affect the accuracy and application of the results, particularly in places with highly variable climatic conditions where samples were collected. Understanding the complex biological processes of algal populations and how they respond to environmental factors requires careful consideration of the best locations to gather samples. Each of these areas demonstrates different urbanized and nutrient-rich characteristics. The study sites selected for the sampling were the Negombo "Mora Wala" (7°12'14.73"N, 79°49'2.49"E) (November 2022), "Thalpe"beach (5°59'53.24"N, 80°16'58.82"E)(March 2023), Baticoloa lagoon (7°42'40.52"N, 81°41'22.39"E)(May 2023).

B. Algae Growing Experiments

The lab space was kept clean and free from contaminants that could have affected the experiment. Algae require major essential elements (Carbon (C), Nitrogen (N), Phosphorus (P), Sulphur (S), Potassium (K), Magnesium (Mg) and Calcium (Ca)) for their maximum growth [7]. Thus, 1g of "Eppawala" rock phosphate (ERP) was used as the nutrient source of the algae thrice a week throughout the experiment period since ERP has high phosphate content. Aeration provided the algae with a steady supply of carbon dioxide, which was essential for photosynthesis, and helped prevent the buildup of excess oxygen, which could have hindered algae growth. The aeration was done using a two-way aerator pump (SDA-2800). The samples were positioned near a window to provide natural sunlight. Light was a crucial factor in photosynthesis, and the intensity and duration of light exposure could have affected the growth rate and pigment production in algae. pH, temperature, total dissolved solids (TDS) concentration, salinity and electrical conductivity (EC) were monitored every day at 4 pm.

C. Performance Evaluation of Mature Compost in Desalination Process

In order to evaluate the effectiveness of mature compost in the desalination process, an experimental filter bed was meticulously constructed and rigorously tested. The apparatus consisted of a plastic bucket measuring 45 cm in height and 35 cm in diameter, equipped with an outlet fixed at the bottom to facilitate water drainage. The selected filter medium for this study was mature compost, which was sourced from the municipal council in Negombo. And the brackish water was taken from the Negombo "Morawala". The filter bed was designed with a specific layering approach. At the base of the bucket, a 5 cm thick layer of fine metal particles, each approximately 2 cm in diameter, was meticulously arranged. On top of this metal layer, a generous 10 cm thick layer of mature compost was carefully placed. The experiment was conducted over a duration of two weeks, during which salinity levels in the filtrate samples were assiduously measured. This vital data collection process done daily at 4. 00 pm.

D. Laboratory Scale Bioreactor Setup

A potable trapezoidal pit shape model was constructed 90 cm top square and 30 cm bottom square with 30 cm depth as shown in Figure 1 [5]. This structure was covered with steal wire mesh. Bottom steal wire mesh was used to release the water. The biofilter system was fabricated with a 15-cm clay polythene clay composite liner and 5 cm mature compost layer and algae layer as shown in Figure 1(a, b). The research was conducted for a period of two weeks, during which various water quality parameters were systematically measured both inside the biofiltration system and the filtrate. These measurements included pH (using pH meter Thermo Scientific, model Orion 2 star), Electrical conductivity (EC), total dissolved solids (TDS)(EC and TDS meter, Thermo Orient Model 145 A), total suspended solids (TSS) using Gravimetric method (using APHA Method 2540-G), salinity (using Refractometer RHA-100ATC) , and total solids using oven dried method (using APHA Method 2540-G) (Table 1). Measurements were consistently taken daily at 4.00 pm. Removal efficiency was calculated using Eq. 1.

$$Removal\ efficiency\,\% = \frac{C_{in} - C_{out}}{C_{in}} \times 100 \qquad (1)$$

Where, C_{in} = inlet concentration, C_{out} = outlet/filtrate concentration

III. Results and Discussion

The brackish water in Negombo "Morawala", which used as the source water to the laboratory scale setup had specific starting characteristics, with an EC of 17,910 ms/cm, a salinity of 35‰, a TDS concentration of 8,957 ppm, and a

slightly alkaline pH of 7.76. For the laboratory-scale setup of this study, the location of choice was the Negombo "Morawala" area, which provided convenient accessibility for in-depth analysis and observation of algae abundance. The research extended from November to March, a period during which the Negombo Lagoon exhibited richness in macroalgae populations. However, it is noteworthy that after the month of April, a significant decline in the presence of macroalgae blooms was observed in the Negombo "Morawala" area, this decline may be related to seasonal variations, with the period from November to March being characterized by favorable conditions such as temperature, light availability, and nutrient levels, which are conducive to the growth and proliferation of macroalgae. As these conditions change with the onset of spring and the transition into warmer months, macroalgae populations may naturally recede.

In this context, mature compost proved to be a valuable asset due to its rich microbial community. These microorganisms played a pivotal role in breaking down and metabolizing the organic matter present in the water. Remarkably, Thus, 65±12% salt reducing efficiency was observed in the compost.

The liner system in use exhibited a hydraulic conductivity of 2.64×10^{-7} cm/sec. This set the stage for an innovative approach to salt removal. Within the bioreactor situated above the liner system, the presence of algae was noteworthy. Despite the moderate salinity (35‰), the algae not only survived but also actively participated in reducing the salt content. It achieved a commendable 60% reduction through the uptake of salts, demonstrating its remarkable adaptability to challenging conditions.

The EC of the bioreactor, averaging 18,084 ± 1,612.68 mS/cm, contrasted markedly with the much lower EC observed in the filtrate, which averaged 2,116.5 ± 1,036.39 mS/cm. This substantial decrease in EC within the filtrate highlights the effectiveness of the desalination process in reducing the concentration of ions and total dissolved solids, further emphasizing its application in producing low-conductivity water. Salinity levels within the bioreactor remained relatively constant at 24 ± 0.08%, while in the filtrate, salinity was substantially reduced to an average of 4 ± 0.02% (Table 1). This remarkable reduction in salinity emphasizes the potential of the biofilter system for desalination, indicating its suitability for generating low-salinity water, which can be crucial in regions with freshwater scarcity. The bioreactor contained a substantial concentration of total dissolved solids (TDS), averaging 8,991.2 ± 780.66 ppm, whereas the filtrate exhibited significantly lower TDS levels, averaging 1,296.6 ± 508.20 ppm. This pronounced decrease in TDS in the filtrate underscores the bio-filter's capability to effectively remove dissolved solids from the water. TSS concentration within the bioreactor measured 14,100 ± 3,446 mg/l, whereas the filtrate showed lower TSS levels, averaging 3,200 ± 1,475 mg/l. This discrepancy between the two indicates that some suspended solids may still be present in the bioreactor, suggesting the need for additional post-treatment methods, such as sedimentation or enhanced filtration, to further clarify the water. TS concentration within the bioreactor were significantly higher, with an average of 93,800 ± 44,842 mg/l, compared to the lower TS values in the filtrate, averaging 44,300 ± 28,771 mg/l. The substantial reduction in TS within the filtrate reinforces the efficiency of the biofilter system in reducing the concentration of solid particulates in the water. The overall success of the system became even more evident when a laboratory-scale biofiltration setup, incorporating algae, mature compost, and clay polyethylene clay liners, was put to the test. This integrated approach resulted in an impressive 90% removal of salt from the saline water, as clearly illustrated in the accompanying figures and graphs. In essence, the collaborative actions of mature compost, algae, and the microbial community allowed for a highly effective and sustainable approach to tackling the salinity issue in the water, marking a promising advancement in brackish water treatment. The development of sustainable algae harvesting techniques for large-scale applications is imperative. This necessitates a comprehensive focus on optimizing the kinetics of harvesting processes and exploring the potential integration of carbon sources.

TABLE 1: PERFORMANCES OF THE BIOFILTER SYSTEM DURING THE STUDY PERIOD

Parameter	Inside the Bioreactor	Filtrate	Removal efficiency (%)
pH	8.96 ±0.73	9.32±0.27	-
Temperature(°C)	29.54 ±1.40	30.46±2.31	-
EC (ms/cm)	18084±1612.68	2116.5±1036.4	88.29±5.4
Salinity (‰)	24±0.08	4±0.02	80.55±9.47
TDS (ppm)	8991.2±780.66	1296.6±508.20	85.63±5.29
TSS (mg/l)	14100±3446	3200±1475	75.96±10.84
TS (mg/l)	93800±44842	44300±28771	32.38±36.30

IV. CONCLUSION

This study narrows down to combine; mature compost, algae and the liner system to remove 90% of the salinity. The findings from this study demonstrate the potential of naturally grown microalgae to effectively reduce salinity levels in brackish water. This approach not only minimizes the need for energy-intensive cultivation processes but also maintains the ecological integrity of the lagoon ecosystem. The microalgae, adapting to the local conditions, showcased their resilience and ability to thrive in the given environmental constraints, thereby offering a practical solution for saline water treatment. However, it is clear that a more controlled and efficient culturing system for microalgae is essential. While our experiment successfully utilized the natural environment, a dedicated culturing system would offer advantages in terms of scalability, optimization, and reliability. Therefore, it is recommended that future studies and applications incorporate a controlled microalgae culturing system that can be tailored to the specific needs of the brackish water treatment process. And the hydraulic conductivity of the liner system should be increased by modifying the compaction densities and increasing the amount of waste polythene in the composite liner. In essence, brackish water with the required

combination of treatment methods can be used for irrigation of salt loving crops as well as crop requiring good quality water, industrial use or even for domestic use.

V. Acknowledgement

The Authors are most grateful to the Research Funds of the Sri Lanka Technological Campus for financial support.

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FULL PAPERS

2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

Modal Analysis of Rectangular-Shaped Concrete Liquid Storage Tanks with Baffles

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***Abstract*—This study focuses on the modal analysis of rectangular-shaped concrete fluid storage tanks with internal baffles. Liquid sloshing, occurring during earthquakes, presents engineering problems due to the interaction between the liquid and the tank. Modal analysis is employed to determine the fundamental frequency characteristics, validating the results with previous work. It is figured that baffles can be employed to distance the excitation frequency from both the fundamental resonant frequency and any other resonant frequency. Ansys software is used to examine the effect of internal objects on mode shapes and natural frequencies in a concrete rectangular fluid tank system.**

Keywords—Modal analysis, liquid storage tanks, baffles

I. Introduction

Modal analysis is a parameter which is fundamental to any system subjected to dynamic loading. Sloshing characteristics such as mode shapes and natural frequencies depend on the material characteristics and geometry of the liquid system, liquid-filled depths, and the restraint types at the tank boundaries. The presence of internal submerged components in the tank alters the total characteristics of the free and forced vibration systems.

Several studies related to fluid sloshing have been carried out analytically, numerically, and experimentally, but a limited number of studies reported on the modal analysis considering the presence of internal objects. Free vibration characteristics are attained using the non-linear formulation. In the baffled scenario, the size and location of the submerged baffle are varied.

II. Mathematical Background of Model Analysis

A. Modal Analysis-Acoustics

Finite Element Analysis (FEA) can be employed to compute the response of a complex structure subjected to forcing functions, which may involve an acoustic source or a distribution of mechanical forces. FEA of acoustic systems entails the discretization of the acoustic volume into elements and nodes. A confined acoustic space might be surrounded by rigid walls, a flexible structure, or walls that deliver acoustic damping.

The finite element method (FEM) considers the mutual interaction between a structure and a fluid whether it's air or water. In challenges involving acoustic fluid-structure interaction, we must account for the equations governing structural dynamics. This includes incorporating the mathematical representation of the system's acoustics as described by the Navier-Stokes equations of fluid momentum and the flow continuity equation. The discretized equation for structural dynamics can be formulated using structural finite elements. The fluid momentum and continuity equations undergo simplification to derive the acoustic wave equation, including assumptions such as fluid compressibility and inviscidity as in [1].

The acoustic wave equation serves as a tool for describing the acoustic response of the fluid. Appropriate acoustic finite elements can be developed by discretizing the lossless wave equation through the Galerkin method. There are two formulations of finite elements that are used to analyze acoustic problems considering either pressure or displacement as the unknown. The most common and used FE in this modal analysis is the pressure-formulated element as in [1].

B. Pressure Formulated Acoustic Elements

The acoustic pressure P in a FE can be shown as;

$$P = \sum_{i=1}^{m} NiPi \quad (1)$$

Where N_i is a set of linear shape functions, P_i are acoustic nodal pressures at node i, and m is the number of nodes forming the element. For pressure-formulated acoustic elements, the FE equation for the fluid is,

$$[M_f]\{\ddot{P}\} + [K_f]\{P\} = \{F_f\} \quad (2)$$

Where $[K_f]$ is the equivalent fluid stiffness matrix, $[M_f]$ is the equivalent fluid mass matrix, F_f is a vector of applied fluid loads, P is a vector of unknown nodal acoustic pressures, and $\ddot{P}$ is a vector of the second derivative of acoustic pressure with respect to time. FLUID 220 is one of the available acoustic elements in ANSYS [2], and used in the modal acoustic analysis as a fluid domain [1].

C. Fluid-Structure Interactions (F-S-I)

Standard pressure-formulated acoustic elements can be connected to structural elements so that the two become coupled, hence the acoustic pressure acts on a structure which causes it to vibrate, and also is the converse where a structure which vibrates causes sound to be produced in an acoustic fluid.

The Equation for the coupled fluid-structure interaction is,

$$[M_s]\{\ddot{U}\} + [K_s]\{U\} = \{F_s\} \quad (3)$$

Where $[K_s]$ is the structural stiffness matrix, [M] is the structural mass matrix, $\{F_s\}$ is a vector of applied structural loads, {U} is a vector of unknown nodal displacements and $\{\ddot{U}\}$ is a vector of the second derivative of displacements

with respect to time, equivalent to the acceleration of the nodes. The F-S-I occurs at the interface between the structure and the acoustic elements, where the acoustic pressure exerts a force on the structure and the motion of the structure produces a pressure. To incorporate the coupling between the structure and the acoustic fluid, additional terms are added to the equations of motion for the structure and fluid (of density, ρ_o), respectively, as given below [1].

$$[M_s]\{\ddot{U}\} + [K_s]\{U\} = \{F_s\} + [R]\{P\} \quad (4)$$

$$[M_f]\{\ddot{P}\} + [K_f]\{P\} = \{F_f\} - \rho_o\,[R]^T\{\ddot{U}\} \quad (5)$$

Here, [R] is the coupling matrix that accounts for the effective surface area associated with each node on the fluid-structure interface. The above equations can be formed as matrices as given in Eq. (6) [1];

$$\begin{bmatrix} Ms & 0 \\ \rho_o R^T & Mf \end{bmatrix}\begin{Bmatrix} \ddot{U} \\ \ddot{P} \end{Bmatrix} + \begin{bmatrix} Cs & 0 \\ 0 & Cf \end{bmatrix}\begin{Bmatrix} \dot{U} \\ \dot{P} \end{Bmatrix} + \begin{bmatrix} Ks & -R \\ 0 & Kf \end{bmatrix}\begin{Bmatrix} U \\ P \end{Bmatrix} = \begin{Bmatrix} Fs \\ Ff \end{Bmatrix} \quad (6)$$

Where $[C_s]$ and $[C_f]$ are structural and acoustic damping matrices.

The fluid-structure interaction method described above accounts for two-way coupling between structures and fluids. When using this coupling in FEA, it is required to construct the model to represent the interface between the fluid and the structure. The elements for the structural partition contain displacement Degree of Freedoms (DOFs). At the interface between the acoustic fluid and the structure, there is a single layer of acoustic elements that have pressure and displacement DOFs. It is this thin layer of elements that enables the mutual coupling between the vibration of the structure and the pressure response in the liquid. While it is feasible to employ acoustic elements with both pressure and displacement DOFs throughout the entire acoustic field, this is unnecessary and leads to prolonged solution times. A more efficient strategy involves utilizing elements with both types of DOFs only at the fluid-structure interfaces and employing acoustic elements with solely a pressure DOF for the remaining acoustic field. When utilizing ANSYS software [2], it becomes imperative to explicitly specify the contact surfaces between the structure and the fluid by using the Fluid-Structure-Interface (FSI).

III. Model Analysis of Concrete Rectangular-Shaped Tanks

A. Finite Element Modelling

In Ansys workbench, the ACT extension modal acoustics is used. Frictionless contact between fluid and tank, free surface, fixed base, fluid-acoustic and tank-physics configuration, gravity, and fluid-solid interface are considered. An acoustic analysis can compute either the propagation properties of pure acoustic waves within a specified environment or the coupled acoustic F-S-I using either the Helmholtz or convective wave equation as in [1]. Four types of elements used; SOLID185 – for 3-D modelling of solid structures, FLUID220 – for 3-D modelling of fluid medium, TARGE170 – denotes various 3-D target surfaces for the associated contact elements, CONTA174 – denotes contact and sliding between target surfaces and a deformable surface defined by this element as in [1].

B. Modal Analysis Validation

The hydrodynamic pressure resulting from dynamic loading is divided into impulsive and convective components. The impulsive pressure arises from the liquid segment accelerating with the tank, while the convective pressure is generated by the oscillation of the liquid portion within the tank. The present model, slightly modified, has been embraced in many codes and standards. To validate the FE model, the fundamental periods of both the impulsive and convective modes for the rectangular tank were determined and subsequently compared with the analytical solution proposed by Housner. [3] along with selected design codes such as EC8, ACI 350.3, and ECP 201.

1) Description of the model

A fixed base shallow rectangular concrete tank with dimensions of 30.0 m length (Lz), 15.0 m width (Lx) and, 6.0 m wall height (Hw) has been used. The wall thickness of the tank (tw) is 0.60 m and the height of the liquid inside the tank (H_L) is 5.50 m. This tank was previously used by several researchers such as Kianoush and Chen [4], Chen and Kianoush [5], Kim et al. [6] and, Yazdanian and Ghasemi [7]. A schematic configuration of the tank is shown in Fig. 1. The material properties of the concrete and liquid are listed in Table 1.

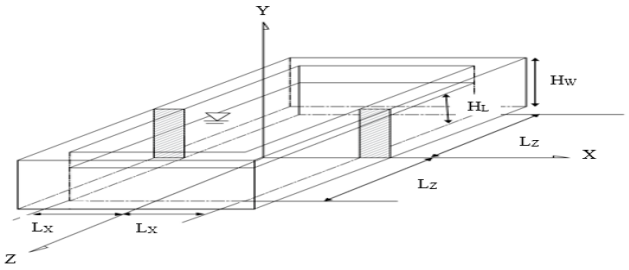


Fig. 1. An illustrative diagram representing the tank under consideration.

TABLE 1. MATERIAL PROPERTIES OF LIQUID AND TANK

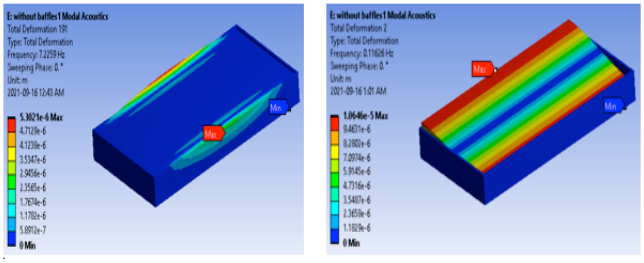
Concrete			Liquid	
Young's modulus (E_c)	***Density ρ_c***	***Poisson's ratio υ***	***Density ρ_w***	***Bulk modulus***
2.644×10^{10} Pa	2300 kg/m^3	0.17	1000kg/m^3	2.1×10^9 Pa

2) Comparison of FE results

The fundamental periods of both the impulsive and convective modes for the shallow rectangular tank were determined and compared with the analytical solution proposed by Housner [3], in Safaa et al. [8]. Hence, the modal analysis was employed and the resulting natural frequencies for the impulsive (Ti) and the convective (Tc) modes have been documented in Table 2 and compared with the analytical results. Additionally, the fundamental mode shapes of the shallow rectangular tank are shown in Fig. 2.

TABLE 2. COMPARISON AMONG FE AND ANALYTICAL RESULTS

Fundamental Period(s)	Ansys Simulation Results	Analytical (Housner)	%Difference
Impulsive (Ti)	0.138 sec (7.22 Hz)	0.15	-8.6%
Convective (Tc)	8.60 sec (0.116Hz)	8.56	+0.4%



(a) Impulsive mode shape Ti = 0.138 s (7.22Hz)

(b) Convective mode shape Tc = 8.6 s (0.116Hz)

Fig. 2. Fundamental mode shapes

TABLE 3. EXPRESSIONS FOR CONVECTIVE AND IMPULSIVE TIME PERIODS GIVEN IN DIFFERENT CODES

Reference	Expression	
	Impulsive	***Convective***
Eurocode 8 part 4: equations - A.46 & A.47	$T_i=2\pi\{d_f / g\}^{1/2}$	$T_c = 2\pi\{L/g\}^{1/2} / \{(\pi/2)\tanh((\pi/2)(H/L))\}^{1/2}$
ACI 350.3	$T_i =2\pi\{(W_i + W_w)/g_k\}^{1/2}$	$T_c = 2\pi\{L\}^{1/2} / \{(3.16g)\tanh(3.16(H/L))\}^{1/2}$
ASCE 7	No expressions given	$T_c = 2\pi\{L\}^{1/2} / \{(3.68g)\tanh(3.68(H/L))\}^{1/2}$
ECP - 201	$T_i = 2\pi\{d_f / g\}^{1/2}$	$T_c = 2\pi\{L/g\}^{1/2} / \{(3.16)\tanh((3.16)(H/L))\}^{1/2}$

TABLE 4. COMPARISON BETWEEN ANSYS RESULTS AND DIFFERENT SEISMIC DESIGN CODES FOR THE CONVECTIVE MODE

Design code	Ansys Simulation	EC 8 – part 4	ACI 350.3	ECP-201
T_c (s)	8.6	8.59	8.55	8.55
%Difference	-	-0.1 %	-0.5 %	-0.5%

C. *Parametric Study*

The natural frequencies and mode shapes are figured in two types of tanks, namely, shallow and tall tanks. The dimensions of these tanks are derived from previous works by Kim et al. [6], Kianoush and Chen [4], Chen and Kianoush [5] and, Yazdanian and Ghasemi [7].

In the study by Kim et al [6], the effect of the length-to-height ratio, $2Lz/H_W$ was studied among various geometric factors, while other dimensions and material properties remained constant. The study considered a range of the ratio $1<2Lz/H_W<20$. Fundamental frequencies for different ratios of $2Lz/H_W$ were calculated by 3-dimensional models and compared with those from 2-dimensional models. It was perceived that as the aspect ratio increased, the fundamental frequency converged with that of the 2-dimensional model, irrespective of 3-dimensional restraint conditions. At a ratio of $2Lz/H_W = 10$, the fundamental frequency is closely aligned with that of the 2-dimensional model. Beyond $2Lz/H_W>10$, the change of fundamental frequency became insensitive to the ratio. This indicates that response characteristics do not significantly change in the range of 2Lz/Hw, as corroborated study's results. Peak relative displacement and peak total acceleration at the top of the middle cross-section of the side wall were calculated and presented for varying length-to-height ratios ($2Lz/H_W$).

Even though the outcomes in the study by Kim et al [6] study were derived from time-domain analysis without damping, they clearly indicate a consistent trend. When the ratio $2Lz/H_W$ is higher than 10, the responses tend to remain relatively constant. Conversely, when the ratio is smaller than 10, the responses appear to be significantly affected by the length-to-height ratio. It is important to note that the response itself was not identical to that of the 2-dimensional model, as outlined in the study, where hydrodynamic pressure distributions over the flexible wall surface were plotted for the length-to-height ratio 20. Therefore, the dimensions of two tanks labeled "shallow" and "tall", which demonstrate the outcomes of the influence of $2Lz/H_W$, were considered in this study.

- Shallow tank –

  Lx = 15m, Lz = 30 m (L=60m), Hw = 6m, H_L = d = 5.5m, t_w = 0.6m

- Tall tank –

  Lx = 9.8m, Lz = 28 m (L=56m), Hw = 12.3m, H_L = d = 11.2m, t_w = 1.2m

The investigation involves exploring the impact of submerged baffles on the free vibration characteristics of sloshing by varying their sizes and positions. In Ansys simulation, impulsive and convective fundamentals can be figured without hesitation as the difference of model shapes are obvious. The first few frequencies are considered for each impulsive and convective mode.

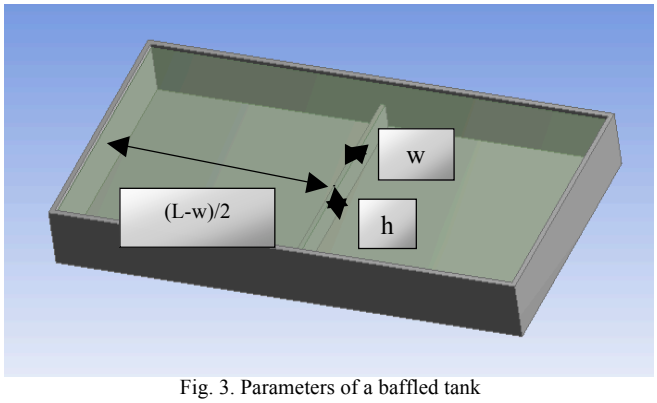


Fig. 3. Parameters of a baffled tank

The effects of centrally placed and off-centered baffle/baffles on the sloshing frequencies and mode shapes are considered. A parametric study is conducted considering the following as variables;

1). Width of baffle to length (w/L)
2). Baffle height to water depth ratio (h/d)
3). Location of the baffle, i.e. 0.5L and 0.25L
4). Number of baffles

TABLE 5. PARAMETERS OF THE RECTANGULAR TANKS

Shallow Tank d / L = 5.5 / 60 = 0.09	h / d = 1.375 / 5.5 = 0.25	h / d = 2.75 / 5.5 = 0.5	h / d = 4.95 / 5.5 = 0.9
	w / L = 0.6 / 60 = 0.01	w / L = 1.8 / 60 = 0.03	h / d = 3.6 / 60 = 0.06
Tall Tank d / L = 11.2 / 56 = 0.2	h / d = 2.8 / 11.2 = 0.25	h / d = 5.6 / 11.2 = 0.5	h / d = 10.08 / 11.2 = 0.9
	w / L = 0.56 / 56 = 0.01	w / L = 1.68 / 56 = 0.03	w / L = 3.36 / 56 = 0.06

1) The Effect of Baffle Width and Tank Length (w/L)

TABLE 6. FREQUENCIES (HZ) ON CENTRALLY PLACED BAFFLE WITH VARYING H/D AND W/L – SHALLOW TANK

d/L	h/d	j = mode number	w/L= 0 (No baffle)	w/L= 0.01	w/L= 0.03	w/L= 0.06
0.09	0.25	1	0.060	0.059	0.059	0.058
		2	0.116	0.116	0.115	0.115
		3	0.116	0.116	0.116	0.116
		4	0.128	0.128	0.128	0.127
		5	0.157	0.157	0.156	0.156
	0.5	1	0.060	0.057	0.056	0.055
		2	0.116	0.116	0.115	0.114
		3	0.116	0.116	0.116	0.115
		4	0.128	0.127	0.127	0.126
		5	0.157	0.156	0.156	0.155
	0.9	1	0.060	0.047	0.042	0.037
		2	0.116	0.115	0.114	0.111
		3	0.116	0.116	0.115	0.114
		4	0.128	0.124	0.123	0.121
		5	0.157	0.144	0.138	0.135

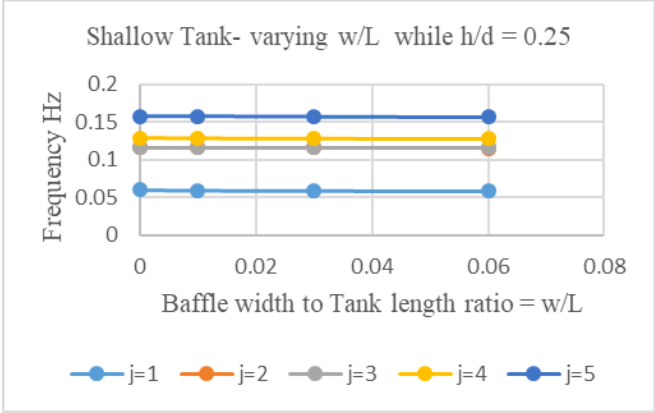


Fig. 4. Shallow Tank- Natural frequency variation of baffle width to tank length (w/L) while baffle height to fluid depth (h/d) =0.25

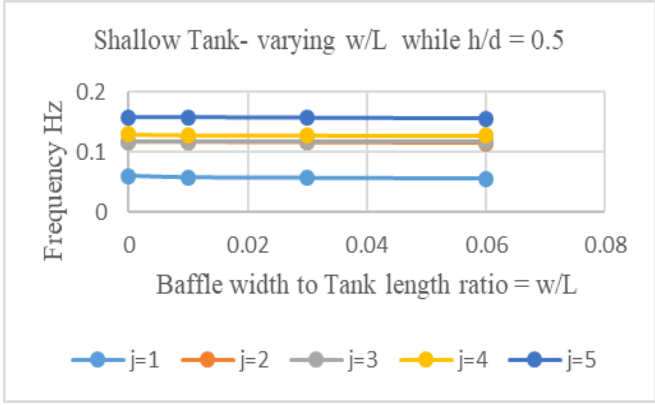


Fig. 5. Shallow Tank- Natural frequency variation of baffle width to tank length (w/L) while baffle height to fluid depth (h/d) =0.5

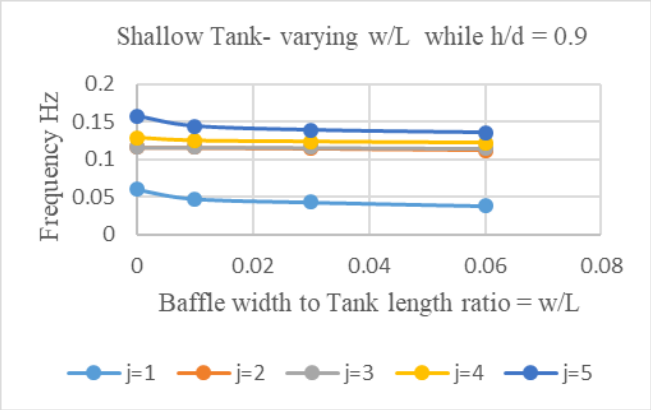


Fig. 6. Shallow Tank- Natural frequency variation of baffle width to tank length (w/L) while baffle height to fluid depth (h/d) =0.9

TABLE 7. FREQUENCIES (HZ) ON CENTRALLY PLACED BAFFLE WITH VARYING H/D AND W/L – TALL TANK

d/L	h/d	j = mode number	w/L= 0 (No baffle)	w/L= 0.01	w/L= 0.03	w/L= 0.06
0.2	0.25	1	0.088	0.086	0.085	0.085
		2	0.154	0.153	0.153	0.153
		3	0.195	0.194	0.193	0.193
		4	0.202	0.199	0.198	0.198
		5	0.202	0.200	0.200	0.200
	0.5	1	0.088	0.062	0.080	0.078
		2	0.154	0.086	0.153	0.153
		3	0.195	0.162	0.193	0.192
		4	0.202	0.195	0.195	0.194
		5	0.202	0.198	0.200	0.200
	0.9	1	0.088	0.061	0.059	0.053
		2	0.154	0.077	0.153	0.150
		3	0.195	0.161	0.182	0.179
		4	0.202	0.188	0.193	0.187
		5	0.202	0.194	0.201	0.2

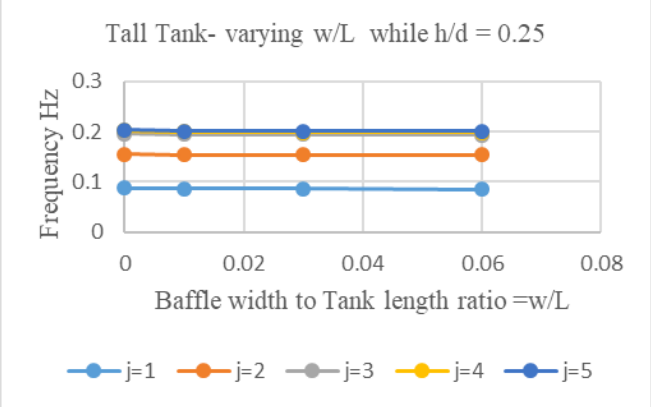


Fig. 7. Tall Tank- Natural frequency variation of baffle width to tank length (w/L) while baffle height to fluid depth (h/d) =0.25

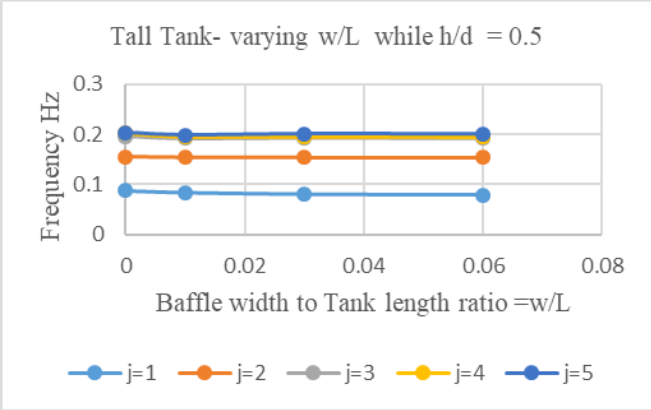


Fig. 8. Tall Tank- Natural frequency variation of baffle width to tank length (w/L) while baffle height to fluid depth (h/d) =0.5

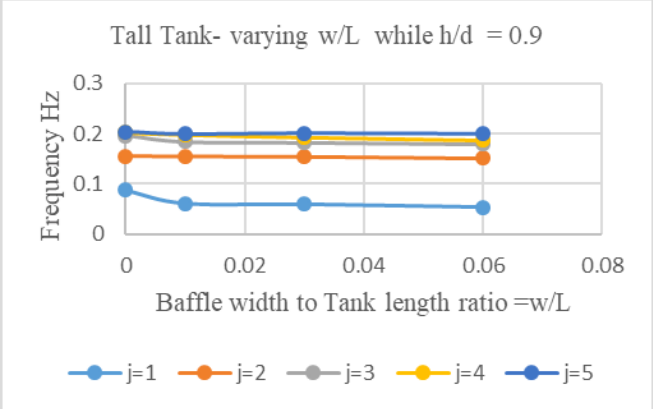


Fig. 9. Tall Tank- Natural frequency variation of baffle width to tank length (w/L) while baffle height to fluid depth (h/d) =0.9

In Fig. 4. – 9., a decrease in natural frequencies is observed with the increase of w/L of the centrally placed baffle of given height for both shallow and tall tanks. While the baffle height to fluid depth (h/d) is around 10-25%, the natural frequency deviation is not significant. However as the ratio of h/d increases beyond 90%, there is a notable impact of the baffle height in the decrease in frequency. Both the fundamental frequency and higher modes exhibit sensitivity to the baffle width.

2) The Effect of Baffle Height and Water Depth (h/d)

To facilitate a comparison of the results, the parameters have been non-dimensionalized. Frequencies for both shallow and tall tanks are compared separately for selected w/L values while varying the h/d values.

For Shallow Tank:

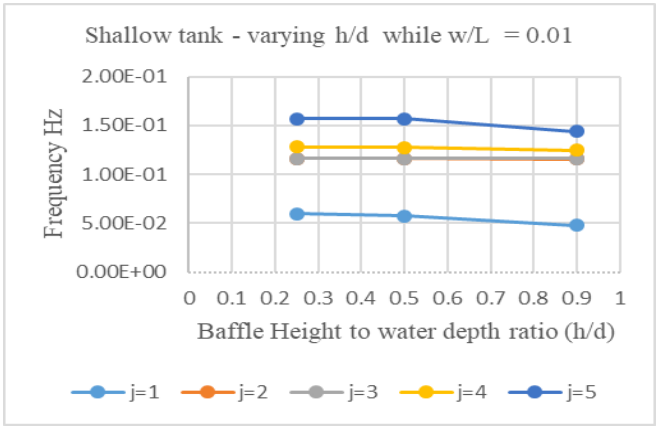


Fig. 10. Shallow Tank- Natural frequency variation of baffle height to tank depth (h/d) while baffle width to tank length (w/L) = 0.01

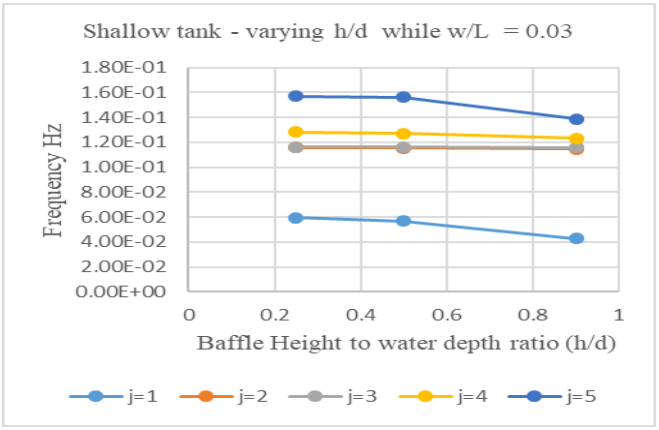


Fig. 11. Shallow Tank- Natural frequency variation of baffle height to tank depth (h/d) while baffle width to tank length (w/L) = 0.03

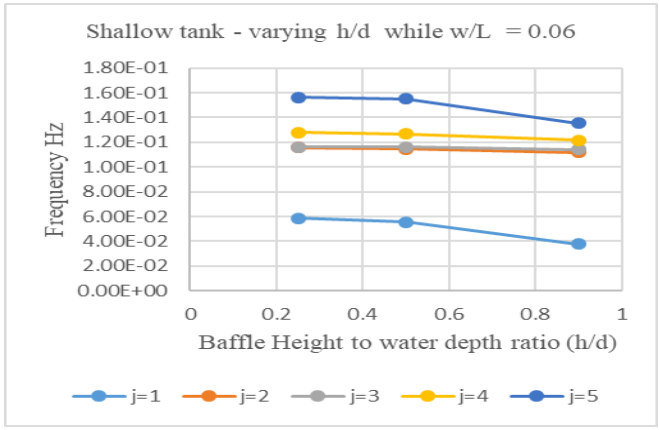


Fig. 12. Shallow Tank- Natural frequency variation of baffle height to tank depth (h/d) while baffle width to tank length (w/L) = 0.06

A decrease in natural frequencies is observed with the increase of centrally placed baffle height of a given width for both shallow and tall tanks. When, the baffle width increases three times and six times compared to the initial width, the natural frequency decreases for all the modes. It is unpredictable for which mode and for which baffle width, a significant deviation in the natural frequency occurs. The fundamental frequency is the most sensitive to baffle height.

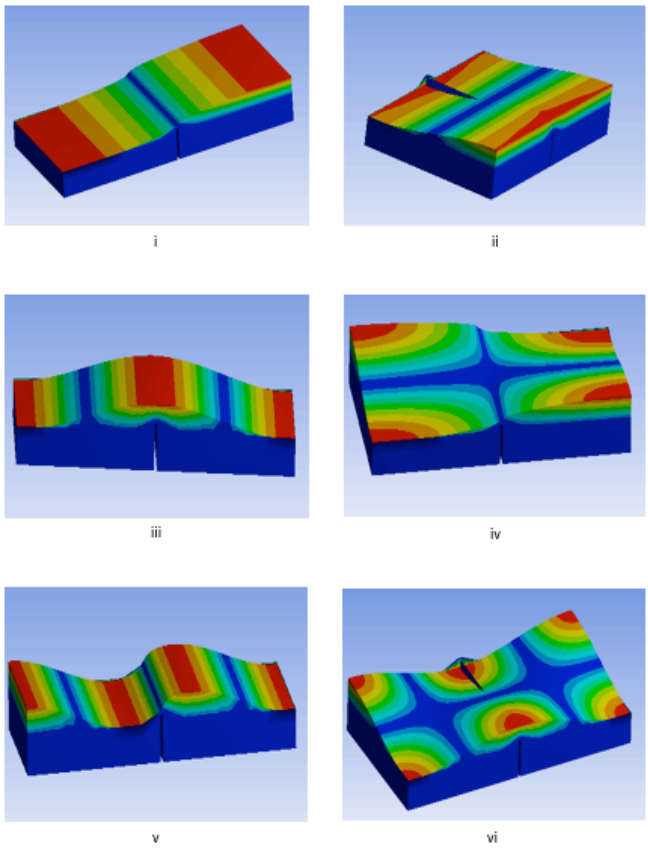


Fig. 13. Typical initial six mode shapes of single-centered shallow baffled tanks (only shown the mode shape of the liquid without tank in above figures)

3) The Effect of Baffle Location Along With Varying Baffle Heights

Centered (0.5L) and off-centered (0.25L) baffle locations with varying baffle heights are considered for the natural frequency comparison for both shallow and tall tanks.

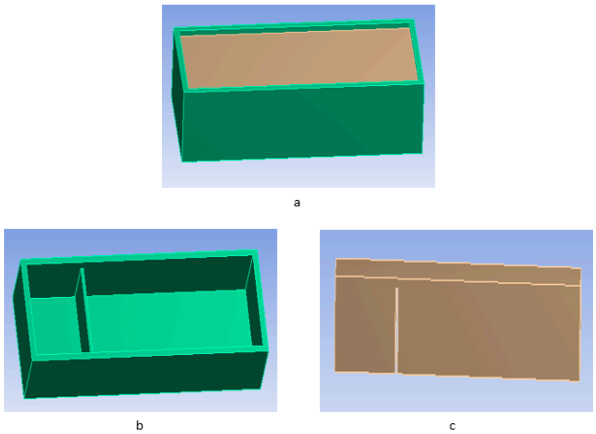


Fig. 14. a) 0.25L Baffled tank filled with fluid, b) 0.25L Baffled tank without fluid, c) Fluid without the tank

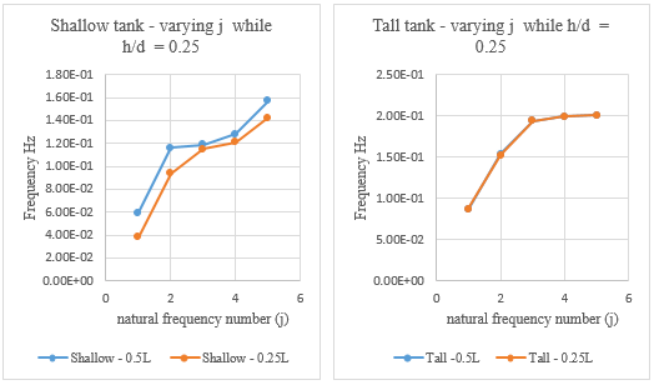


Fig. 15. Frequencies (Hz) on centred (0.5L) and off centred (0.25L) baffles with h/d = 0.25

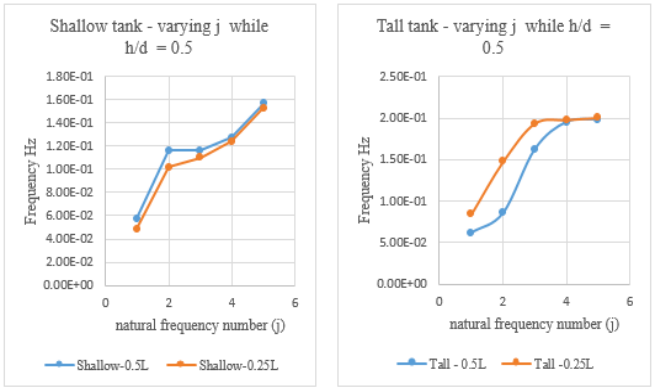


Fig. 16. Frequencies (Hz) on centred (0.5L) and off centred (0.25L) baffles with h/d = 0.5

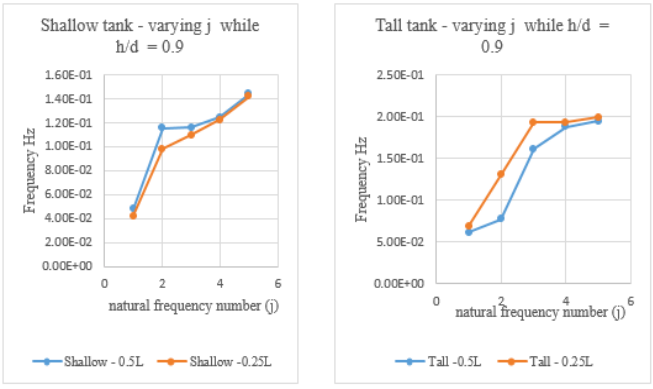


Fig. 17. Frequencies (Hz) on centred (0.5L) and off centred (0.25L) baffles with h/d = 0.9

When considering Fig. 15.–17., for the shallow tank when baffle height is increased, the mode frequencies are increased for both centered (0.5L) and off-centered (0.25L) baffle locations. In each mode (j value), centered (0.5L) baffle frequency is higher than the off-centered (0.25L) baffle frequency.

For the Tall tank when baffle height is increased, the mode frequencies are increased for both centered (0.5L) and off-centered (0.25L) baffle locations. In each mode (j value), off-centered (0.25L) baffle frequency is higher than the centered (0.5L) baffle frequency.

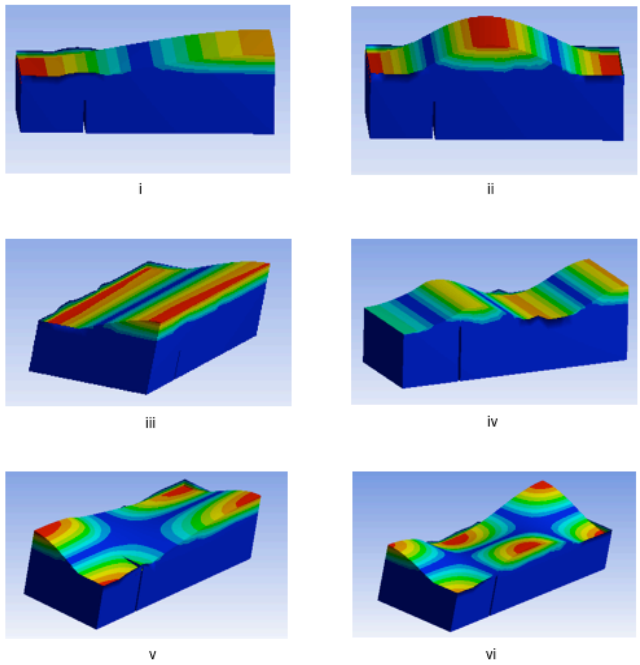


Fig. 18. Typical initial six mode shapes of single 0.25L Tall baffled tanks (only shown the mode shapes of the liquid without the tank)

4) The Effect of the number of Baffles in Tanks for Frequency

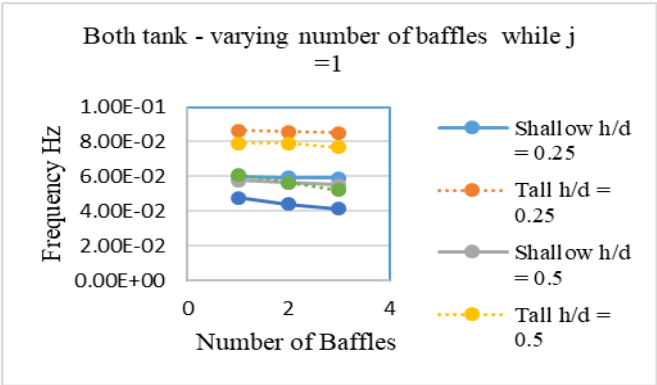


Fig. 19. Frequencies (Hz) on j =1 for varying h/d

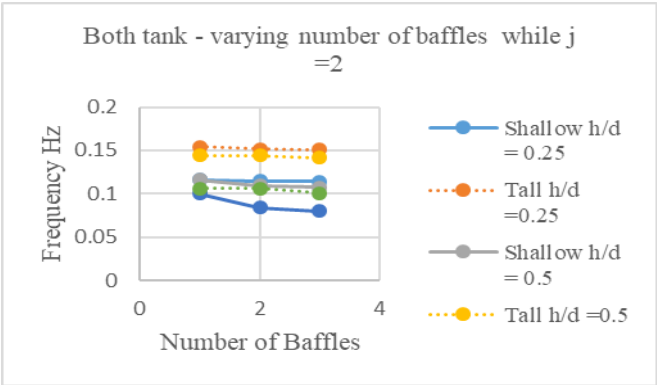


Fig. 20. Frequencies (Hz) on j =2 for varying h/d

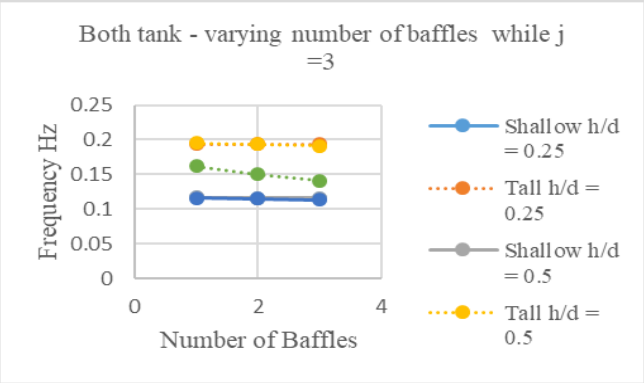


Fig. 21. Frequencies (Hz) on j =3 for varying h/d

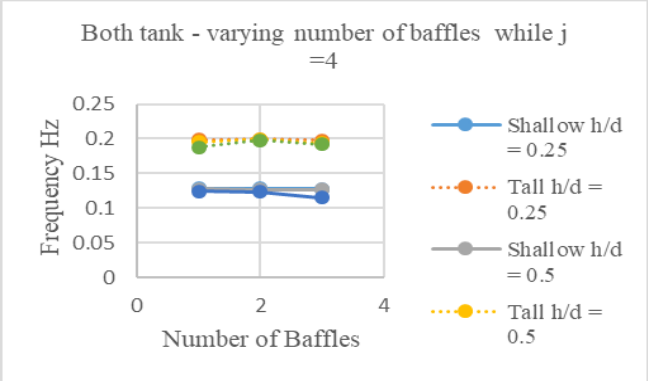


Fig. 22. Frequencies (Hz) on j =4 for varying h/d

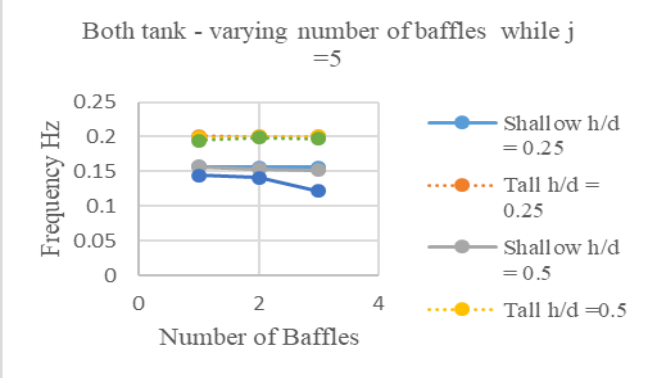


Fig. 23. Frequencies (Hz) on j =5 for varying h/d

In Fig. 19. – 23., the variation of baffle heights is considered. Considering the above figures, the general observation is when the number of baffles is increased, the frequency decreases for each frequency number (j). For the values j = 1,2, there is a significant decrease of frequencies when increasing the number of baffles for almost all the cases; i.e. for shallow and tall tanks h/d = 0.25,0.5 and 0.9.

IV. Conclusions

1. The sloshing frequencies and the elevation of the free surface wave decrease as the height and width of the bottom-mounted submerged baffle increase. Among the baffle dimensions, the fundamental frequency is particularly sensitive to changes.

2. In the case of the shallow tank, when baffle height is increased, the mode frequencies are increased for both centered and off-centered baffle locations. In each mode, centered baffle frequency is higher than the off-centered baffle frequency. For the tall tank when baffle height is increased, the mode frequencies are increased for both centered and off-centered baffle locations. In each mode, off-centered baffle frequency is higher than the centered baffle frequency.

3. Taking into account the three parameters, the influence of the baffle height is prominent on both sloshing resonant frequencies and sloshing elevation.

4. The deviation of sloshing frequencies and mode shapes are mostly similar in the shallow tank and tall tank in similar cases due to the presence of the submerged baffle.

5. Generally, when the number of baffles is increased, the frequency decreases for each frequency number (j). For the values j = 1,2, there is a significant decrease in frequencies when increasing the number of baffles.

The fundamental frequency exerts more force than any other higher frequencies under external excitation. The stability of the considered tank is significantly impacted when the exciting frequency aligns with the fundamental frequency. In such instances, submerged baffles can be utilized to keep the fundamental resonant frequency or for that matter, any other resonant frequency away from the excitation frequency. In terms of constructional suitability, bottom-mounted vertical submerged baffles exhibit a more competitive influence over wall-mounted horizontal baffles. Submerged baffles prove to be more suitable than horizontal baffles in broad tanks, as changes in liquid depth may contravene the utility of horizontal baffles when the liquid level falls below the mounting height of the horizontal baffle. It can be concluded that the fundamental sloshing frequency of liquid in a tank can be kept away from the excitation frequency by adjusting the dimension, location, and number of submerged baffles.

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2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

Effects of Member Sizes on Plastic Hinge Formation in RC Frames by Pushover Analysis

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***Abstract*—In this study, the effects of member sizes on plastic hinge formation in RC frames are investigated by nonlinear pushover analysis. To achieve this objective, a 10-storied building was systematically simulated and analyzed utilizing SAP2000 software. The design of the 10-storied structure adheres to Eurocodes, with consideration of wind loads. Nonlinearity was introduced into the frame structure by implementing Moment (M) and interactive P-M hinges. The analysis process involved the incremental step-by-step displacement of the top node of the structure until reaching the limiting displacement, facilitating the generation of pushover curves. Concurrently, the sequence of plastic hinge formation and the performance points of beams and columns were recorded. This analysis was conducted across a range of member size configurations, providing comprehensive insights into the structural behavior. This study revealed that, when the total cross section area of members are increased by 10.24% 20.98% and 32.22% compared to initial structural model, the maximum base shear forces increased by 13.86%, 28.66%, 42.66% respectively.**

Keywords—Nonlinear pushover analysis, lateral displacement, plastic hinges, base shear

I. INTRODUCTION

Seismic waves and vibrations pose significant threats to building structures and human safety. While encounters with seismic waves are infrequent in Sri Lanka, it remains essential to design buildings that can withstand or mitigate the potential damage caused by these forces. Due to the random and unpredictable nature of seismic forces, a proper structural analysis should be conducted to ensure that buildings can endure the loads imposed by seismic events. Traditional linear elastic analysis methods are often inadequate for this purpose.

In response to this challenge, recent advancements in performance-based engineering have introduced the nonlinear static pushover analysis method, supplanting conventional linear elastic approaches. Pushover analysis can be executed through two primary methods: displacement controlled and force controlled. While the force-controlled method applies a monotonically increasing lateral load pattern to simulate inertial forces induced by seismic waves, the displacement-controlled method offers more accuracy, as it applies a predefined displacement to the structure and conducts the analysis until the target displacement is achieved, thereby establishing the pushover curve or capacity curve, which represents the nonlinear behavior of the structure [1].

A well-executed pushover analysis offers valuable insights into the structural factors influencing performance under seismic events. This type of analysis is likely to provide precise assessments of inelastic deformations, both at the global and local levels, for structures primarily exhibiting fundamental mode oscillations. [2]. Hinges are assigned to replicate the intricate nonlinear behavior inherent in structural components. Within the framework of pushover analysis, various types of hinges are utilized to symbolize distinct aspects of nonlinear behavior within structural elements. Some of the main hinge types are:

(1) Axial Hinge: This type of hinges represents the axial behavior of structural components, encompassing phenomena such as axial deformation and axial forces, primarily observed in columns and other vertical structural elements.
(2) Flexural Hinge: Flexural hinges represent flexural behavior of structural elements, encompassing aspects like bending deformations and bending moments, most prominently observed in beams and columns.
(3) Shear Hinge: Shear hinges represent the shear behavior demonstrated by structural elements, such as shear deformations and shear forces, in horizontal elements like beams and diaphragms.

Hinges account for both material and geometric nonlinearities. Material nonlinearities pertain to the plastic behavior exhibited by the structural material, while geometric nonlinearities consider the deformation characteristics as structures experience substantial displacements and rotations [3].

II. METHODOLOGY

In this study, a multistory building is designed and analyzed using pushover analysis to obtain the load-deformation behavior of the structure. The analysis process involve the incremental step-by-step displacement of the top node until reaching the limiting displacement representing the displacement experienced by the structure when subjected to seismic forces, facilitating the generation of pushover curve. Concurrently, the sequence of plastic hinge formation and the failure mechanisms of beams and columns are recorded. This analysis is conducted across 3 more variant building frame models and a comparative analysis will be conducted using the generated pushover curves of the building models.

A. Design of the Building Frame Structure

Medium rise 10-storey reinforced concrete framed building is considered in this study. The building is designed

adhering to Eurocodes [4, 5, 6], with consideration of wind loads, dead loads and imposed loads from slabs, masonry walls, ceilings and service loads. These loads are applied to the beams of the building frame as distributed loads. The building category is considered as a Category A (residential and commercial) for the design. General details of the building, and material details are shown in the following tables.

TABLE I. GENERAL DETAILS OF THE BUILDING

Parameter	Value
Terrain Category	III
No of Stories	10
Story height	3.5 m
Total height	35 m
No. of bays in X- direction	5
Width of a bay in X- direction	8 m
No. of bays in Y-direction	3
Width of a bay in Y-direction	6 m
Total Width	18 m
Total Length	40 m

TABLE II. CONCRETE MATERIAL DETAILS

Parameter	Value
Concrete grade (fck)	35 MPa
Exposure class	XC1
Modulus of elasticity	34 GPa
Poisson ratio	0.2
Coefficient of thermal expansion	5.5E-06
Shear modulus	14 Gpa
Unit-weight	25 kN/m3

TABLE III. STEEL MATERIAL DETAILS

Parameter	Value
Steel strength	500 MPa
Density	78.5 kN/m3
Modulus of elasticity	200 GPa
Poisson ratio	0.3
Yield strength	500 MPa
Tensile strength	500 MPa

Initial member sizes of the building frame structure were determined adhering to Eurocode standards. SAP2000 [7] software was used to model the frame structure and to verify all members pass the design check for the Eurocode load combinations. The details of the building frame elements are shown in the Tab. 4.

TABLE IV. DETAILS OF THE BUILDING FRAME MEMBERS

Member type		Dimensions(mm)	
		Depth(D)	*Width(W)*
Beam	Edge-Long span	600	400
	Edge-Short span	500	300
	Int. - Long span	600	400
	Int. - Short span	500	300
Column	Corner(1-5)	500	500
	Corner(6-10)	500	500
	Interior(1-5)	650	650
	Interior(6-10)	500	500
	Long Edge(1-5)	600	600
	Long Edge(6-10)	500	500
	Short Edge(1-5)	600	400
	Short Edge(6-10)	500	400

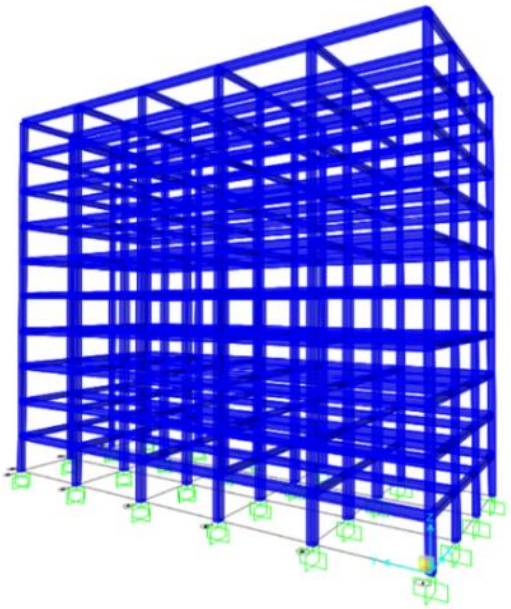


Fig. 1. SAP2000 building Frame model

B. Modelling of the Variant Models

The Initially designed building frame model is modified to obtain three variant building frame models by incrementing the beam and column dimensions of the original frame structure (Model 1). The dimension details of elements in each model are shown in the Table V. Where, LS-Long Span, SS-Short Span, LE- Long Edge, SE-Short Edge, Int.-Interior, Cor.-Corner, D-Depth (mm), W-Width (mm).

TABLE V. MEMBER DIMENSIONS OF THE MODELS

Member type		Model 1		Model 2		Model 3		Model 4	
		D	*W*	*D*	*W*	*D*	*W*	*D*	*W*
Beam	Edge-LS	600	400	625	425	650	450	675	475
	Edge-SS	500	300	525	325	550	350	575	375
	Int - LS	600	400	625	425	650	450	675	475
	Int - SS	500	300	525	325	550	350	575	375
Column	Cor.1-5	500	500	525	525	550	550	575	575
	Cor.6-10	500	500	525	525	550	550	575	575
	Int (1-5)	650	650	675	675	700	700	725	725
	Int(6-10)	500	500	525	525	550	550	575	575
	LE(1-5)	600	600	625	625	650	650	675	675
	LE(6-10)	500	500	525	525	550	550	575	575
	SE(1-5)	600	400	625	425	650	450	675	475
	SE(6-10)	500	400	525	425	550	450	575	475

The percentages of increase of the total cross sectional area of structural members of each model 2,3 and 4 compared to model 1 are as given below,

Model 2 – 10.24%

Model 3 – 20.98%

Model 4 – 32.22%

All the 3 variant building frame models were modelled using SAP2000 software and all the members are verified to pass the design check for the Eurocode load combinations.

C. Hinge Application

Hinges are employed to replicate the intricate nonlinear behavior inherent in structural components. In this study, hinges are assigned to the beams and columns of the frame structures using default hinge properties of SAP2000. The P-M2-M3 hinges are assigned to columns and M3 Hinges are assigned to the beam members as described in FEMA-356 [8]. Concrete column failure condition is selected as flexure/shear condition.

For both column and beam members, hinge locations are assigned with a relative distance of 0.05m from the both ends of the member. For ground level column members, hinges are assigned only at the top end considering that a hinge will not develop at the bottom due to restrain at the bottom. Locations of assigned hinges for a frame section of the building is shown in Fig. 2.

FEMA 356 defines three primary performance levels: immediate occupancy (IO), life safety (LS), and collapse prevention (CP). Under the IO level, non-structural members may exhibit minor cracks, while structural members remain undamaged. The LS level permits limited damage while ensuring life safety, and it maintains the lateral stiffness and rigidity of structural elements. On the other hand, the CP level may involve the collapse of some walls and permanent structural displacements, but it effectively prevents total structural collapse.

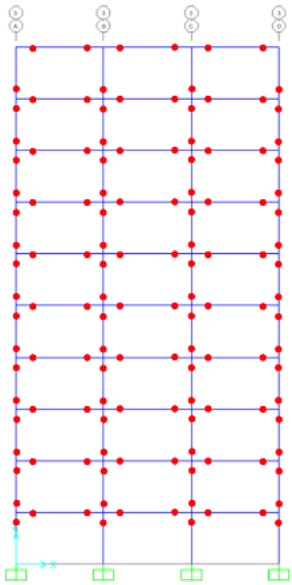


Fig. 2. Assigned hinges of the building frame structure

Fig. 3 illustrates the force-deformation relationship of plastic hinges used to define these performance levels and their associated damage scenarios.

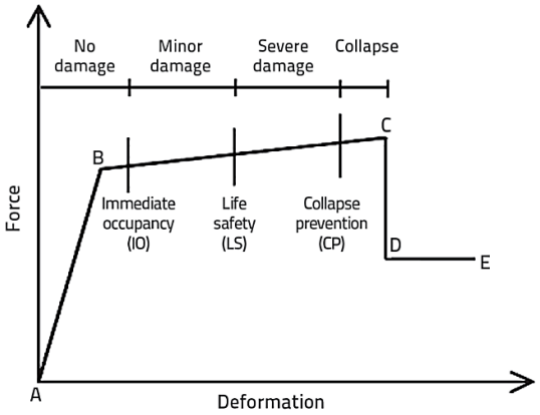


Fig. 3. FEMA-356 performance limits

D. Pushover Analysis

After designing, detailing, and assigning hinges to the reinforced concrete frame structures, a nonlinear pushover analysis is carried out for evaluating the structural seismic response. Pushover analysis is performed by displacement controlled method using SAP2000 software. According to the Eurocodes, it is suggested to push the structure to a top-displacement of 2%-3% h, where h is the height of the building. For this study, 800mm is selected as the monitored displacement magnitude which is 2.3% of the total height.

Control node is the location used to monitor displacements of the structure. Considering the center of gravity of the building frame structure, the assigned control nodes for the analysis are the top two nodes at the edge of the middle frames as shown in the Fig. 4.

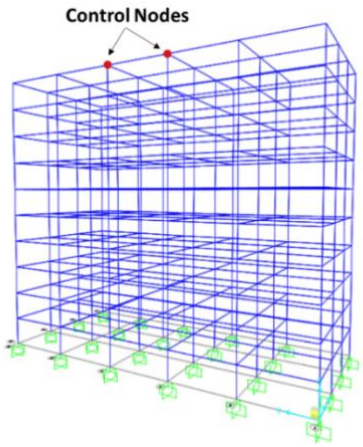


Fig.4. Control nodes of the structure

P-delta effect is considered in the analysis due to lateral deformation of the columns during the pushover. Number of pushover steps determines the accuracy and better capturing of the structural behavior. As the number of steps increases, the analysis can better capture the gradual development of plastic deformation and failure mechanisms in the structure. This is essential for understanding the building's actual response under lateral loads. In this study, Pushover analysis is performed for a minimum of 30 saved steps.

III. Reesults and Discussions

A. Pushover Curves

The Pushover curves (capacity curves) obtained from the pushover analysis as displayed in the Fig. 5 illustrate similar characteristics for all four building models. Initially the structures behave linearly until a displacement of approximately 0.04m where it tend to show higher base shear increments with the displacement. Then the curves gradually deviate from linearity as the beams and columns experience inelastic behaviors, where it tend to show low rate of the base shear increment with the displacement.

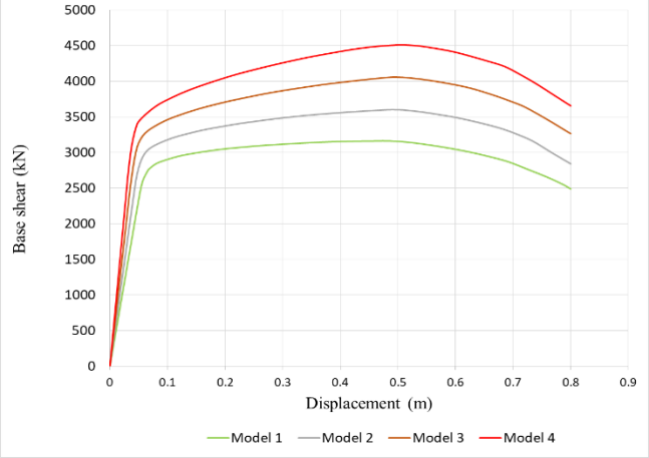


Fig. 5. Pushover curves of the building models

It is observed that the base shear force is increased from model 1 to model 4, which denotes that base shear force increases with the increase of the member sizes. The maximum base shear force recorded and increased percentage of base shear force compared to model 1 for the respective building models are shown in the Table VI. Furthermore, it is observed that the displacements corresponding to the maximum base shear force has increased from model 1 to 4 as shown in the Table VI.

TABLE VI. Recorded Maximum Base Shear Forces of the Models

Model No.	**Displacement (m)**	**Maximum Base shear force (kN)**	**Percentage of base shear force increment (%)**
Model 1	0.472	3161.9	-
Model 2	0.490	3600.3	13.86
Model 3	0.493	4057.9	28.33
Model 4	0.509	4510.5	42.65

B. Hinge Formation at Performance Levels

Hinge formation in frame elements of the 4 building frame models at the Performance levels; Immediate Occupancy (IO), Life Safety (LS), and Collapse Prevention (CP) as per FEMA-356 is shown in Fig. 6. As it progress from model 1 to model 4, base shear value has increased at formation of hinges for B-IO, IO-LS and C Performance levels.

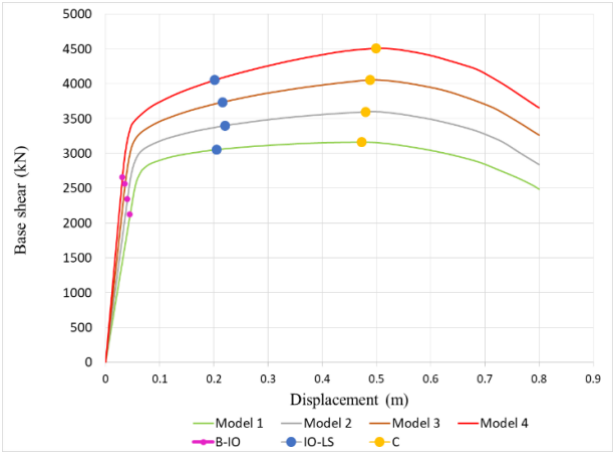


Fig. 6. Formation of hinges at performance levels as per FEMA-356

Observations reveal a slight decrease in hinge formation displacement within the B and Immediate Occupancy performance level as transition from model 1 to model 4 is considered. This suggests that B-IO hinges form at relatively smaller displacement values as member sizes increase.

Furthermore, it is evident that the displacement at the hinge formation between the IO -LS performance levels is approximately consistent in model 1 and model 4, with slightly higher displacement values observed in model 2 and model 3.

Moreover, as we consider the displacement at hinge formation beyond the critical Collapse (C) performance level, it becomes apparent that there is an increase from model 1 to model 4. This implies that hinges surpassing the Collapse performance level form at slightly higher displacement values as member sizes increase. Table VII includes the displacements and base shear forces associated with hinge formation at performance limits corresponding to the building frame models.

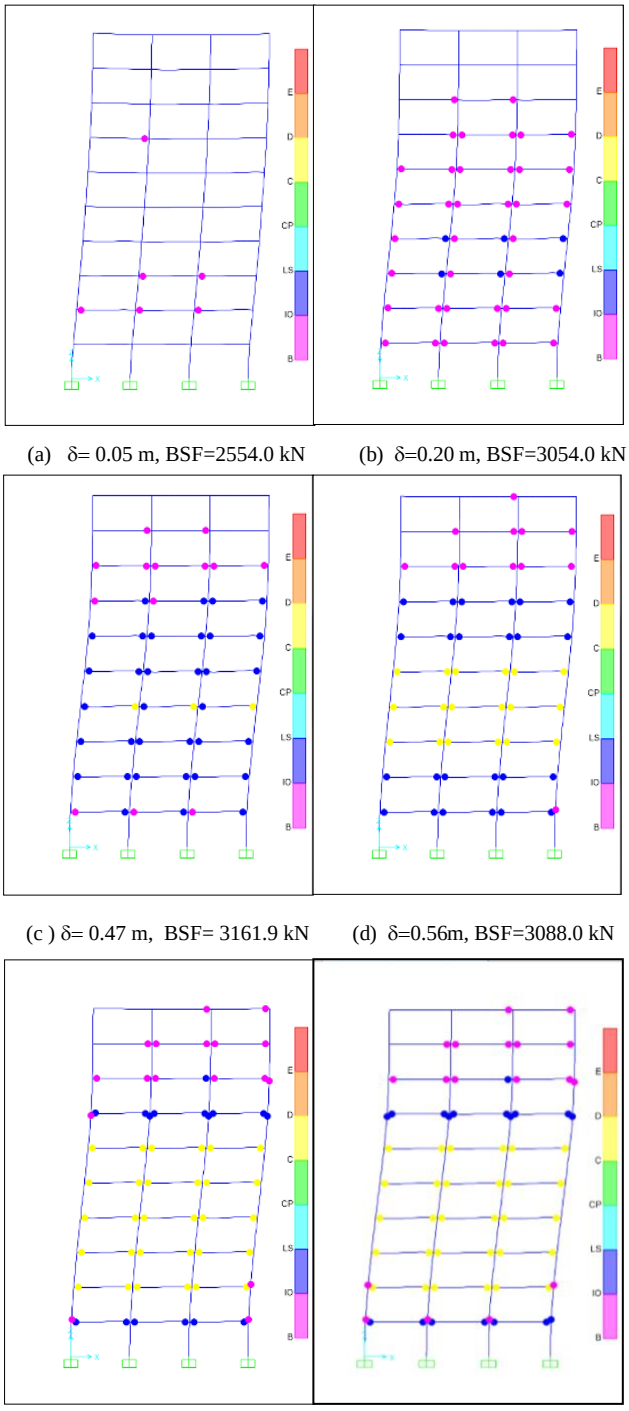
TABLE VII. DISPLACEMENT AND BASE SHEAR FORCES ASSOCIATED WITH HINGE FORMATION AT PERFORMANCE LIMITS

	B-IO		IO -LS		C-D	
	Displacement (mm)	*Base Force (kN)*	*Displacement (mm)*	*Base Force (kN)*	*Displacement (mm)*	*Base Force (kN)*
Model 1	45	2121.8	204	3054.0	472	3161.9
Model 2	40	2342.1	220	3399.1	480	3598.3
Model 3	36	2562.5	215	3736.7	488	4056.9
Model 4	31	2654.6	201	4052.4	498	4509.4

C. Hinge Formation Pattern and Sequence

Hinge formation sequence in the interior frame of model 1 is shown in Fig. 6. Where δ denotes control node displacement and 'BSF' denotes the base shear force. Hinge formation pattern in the columns and beams of every model is generally similar with slight deviations. While performing the pushover analysis, plastic hinges start to form at beam ends of the bottom most stories of the building frame structure around a displacement, δ, of around 0.05m, as shown in Fig. 6(a), then eventually plastic hinges of beams starts forming ascending the story levels as shown in Fig. 6(b). Initial formation of plastic hinges in beams passing IO limit is observed at story level 3, 4 at around a displacement of 0.2m as shown in the Fig. 6(b), eventually forming up to the 7,8 story levels as shown in Fig. 6(c). Plastic hinges initiate to pass the collapse limit at beam ends of story level 5 around a displacement of 0.5m as shown in Fig. 6(c) and eventually transforming every beam hinge at 2nd story to 6th story level to pass the collapse limit shown in the Fig. 6(e).

When comparing the column hinge formation of each model, it is observed that column hinges initiate to form after beam hinges pass the collapse limit for the model 1, 2 and 3 as shown in Fig. 7(a), Fig. 7(b) and Fig. 7(c). But in model 4, column hinges initiate to form before beam hinges reaching collapse limit as shown in Fig. 7(d). Thereby, it is evident that as the member sizes of the frame increases, tendency to form column hinges is less while the beam hinges are passing collapse limit.



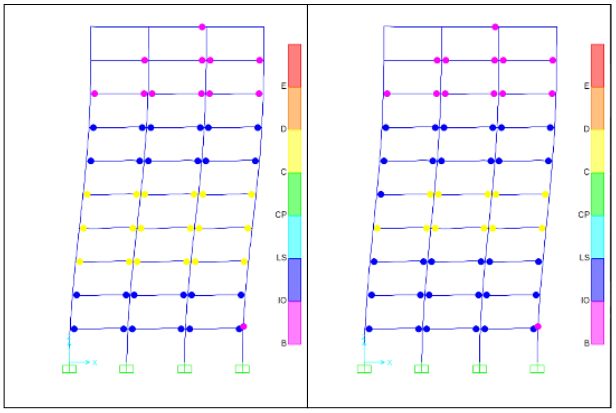
(a) δ= 0.05 m, BSF=2554.0 kN (b) δ=0.20 m, BSF=3054.0 kN

(c) δ= 0.47 m, BSF= 3161.9 kN (d) δ=0.56m, BSF=3088.0 kN

(e) δ= 0.75m, BSF= 2651.9 kN (f) δ=0.80m, BSF= 2487.1kN

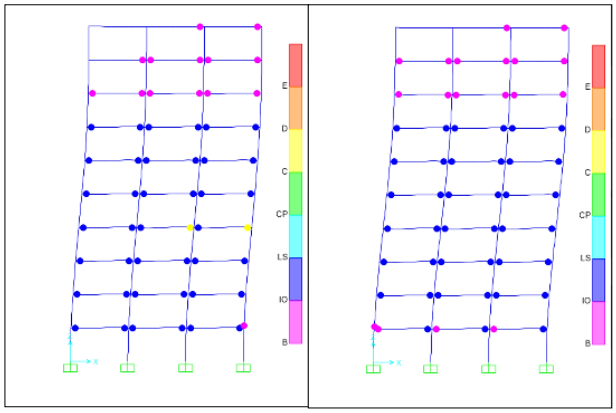
Fig. 6. Plastic hinge formation (Model 1)

Furthermore, at the first column hinge formation, it is observed that the top node displacement is decreased and base shear force get increased when transition from model 1 to model 4.



(a) Model 1
δ= 0.56 m, BSF= 3088.0 kN

(b) Model 2
(b). δ=0.51 m, BSF- 3595.2 kN



(c) Model 3
δ= 0.48m, BSF= 4056.9 kN

(d) Model 4
δ=0.46m, BSF=4489.6 kN

Fig. 7. Initiation of plastic hinge formation at columns

IV. Conclusion

Pushover analysis, as demonstrated in this study, is a valuable and straightforward method for accurately capturing the nonlinear responses exhibited by structures, particularly when they undergo inelastic deformations in response to significant lateral displacements. The step-by-step analysis of plastic hinge formation offers a distinctive insight into the hinge formation locations, critical hinges, and hinge formation patterns of these crucial structural elements. The following conclusions can be drawn based on this study.

- When the total cross section area of members are increased by 10.24% 20.98% and 32.22% compared to initial structural model, the corresponding maximum base shear forces increased by 13.86%, 28.66% and 42.66%.
- The displacements corresponding to the maximum base shear force were increased by 3.81%, 4.45% and 7.84% compared to initial structural model as the member sizes were increased.
- When member sizes increased, the number of beam hinges formed surpassing the collapse limit were decreased by the time of initiation of plastic hinge formation in columns.
- The displacement corresponding to the hinges formed at collapse performance level was increased as the member sizes were increased.
- When member sizes were increased, a decrease in the recorded displacement at the initiation of plastic hinge formation in columns was observed and concurrently, there was an increase in the base shear values as member sizes were increased.
- As member sizes increased, there was a notable reduction in the number of beam hinges formed beyond the collapse limit at the beginning of plastic hinge formation in columns.
- As expected, the initiation of plastic hinge formation was occurred in lower-level column members. This emphasizes the importance of prioritizing the adequate strengthening of these columns to enhance their resilience against seismic events.

In future continuation of this study, additional models can be generated by systematically increasing member sizes, thereby producing a broader range of pushover curves. This approach would facilitate the collection of more comprehensive base shear and corresponding displacement data. Subsequently, the gathered data could be used to develop a statistical equation, enabling the estimation of base shear values for given displacements without necessitating a pushover analysis.

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2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

Validity Assessment of Cone Penetrometer To Estimate Liquid Limit and Optimum Moisture Content in Soil Compaction

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***Abstract*—This research article presents a comprehensive study aimed at validating the Cone Penetrometer Method as an alternative to the traditional Casagrande Method for liquid limit determination in geotechnical engineering. The main objective of this study was to assess the accuracy and reliability of the Cone Penetrometer Method and establish a relationship for estimating optimum moisture content using the Cone penetrometer method. A series of laboratory tests were conducted on a range of soil samples, with comparisons drawn between liquid limit results obtained using the above two methods. Accordingly, an equation for Optimum Moisture Content was derived using Liquid limit values of cone penetrometer method.**

Keywords—Liquid limit, casagrande, cone penetrometer, optimum moisture content

I. INTRODUCTION

The determination of liquid limit and optimum moisture content is of paramount importance in geotechnical engineering and construction practices. Evaluation of liquid limit is based on two methods: cone penetrometer and Casagrande method. Casagrande method is the typical and widely used method for measuring Liquid limit; however, there are several limitations in the Casagrande method has several drawbacks, including high operator dependence, the need to predict the amount of groove closure, the difficulty of cutting a perfect groove, a slow pace of operation, a low degree of repeatability, and so on ([1, 2, 4, 5, and 6]). In addition, there is a noted difficulty of adopting Casagrande method to estimate the liquid limit in low plasticity soil due to the fall of the soil particles towards the groove ([7]). Considering all the above, liquid limit estimation using cone penetrometer appears to be an alternative option. However, several researchers ([9], [3], [8]) have pointed out that the liquid limit values found by the cone penetrometer method (LL_{CONE}) and the liquid limit values found by Casagrande method (LL_{CAS}) are not comparable to a good level of accuracy. Therefore, as the first part of this study, the validity assessment of liquid limit estimation using cone penetrometer test has been carried out.

Furthermore, it has been understood that liquid limit may relate to some soil properties applied in civil engineering. Optimum moisture Content (OMC) in soil compaction is one of the most applied soil parameters in construction industry; however, determination of optimum moisture content for soil compaction requires significant effort, time and soil material. Therefore, as the second part of this study an effort has been made to develop a possible relationship between optimum moisture content and liquid limit values estimated from cone penetrometer method as a simple and fast way of determining optimum moisture content for a preliminary level of analysis.

II. VALIDITY ASSESSMENT OF CONE PENETROMETER METHOD AND CASAGRANDE METHOD FOR LIQUID LIMIT DETERMINATION

A. Experimental Procedure

First, in accordance with ASTM guidelines, the suitability of the cone penetrometer for the determination of liquid limit was evaluated using five soil samples that were collected in different locations in and around Colombo in the Western province of Sri Lanka.

All soils samples were categorized using the Unified Soil Classification System (USCS) before the start of the experiments. The liquid limit of each soil sample was then determined using the Casagrande apparatus method, which is described below. After each soil had been sieved using a 0.425 mm (No. 40) sieve, the sample was first mixed with the necessary volume of water and a spatula was used to transfer a portion of the moist soil sample into a metal cup. As seen in Figure 1, the groove opening was subsequently created in the Casagrande method in accordance with ASTM D4318 using a particular grooving tool. In here tests of groove closure were conducted at various blow counts. Water content samples were taken from the precise position of the closure after each groove closure event, and they were then put in containers to be measured for moisture content. After that, the containers with relevant specimens were weighed and put inside an oven. Those specimens were taken out of the oven and precisely weighed after 24 hours. After calculating the moisture content of each specimen, the results were plotted against the total number of blows. Based on the graph, the water content that corresponds to 25 blows is the specimen's liquid limit.

Fig. 1. Determination of liquid limit using Casagrande method

As per the ASTM 3441-16 cone penetrometer method, the apparatus for determining the liquid limit consists of a 35 mm long, 30°stainless steel cone penetrometer and a sliding shaft with a combined mass of 80 g. The soil being tested is combined with water to make a thick, homogeneous paste, which is then let to stand for a complete day. Next, a portion of this paste is poured into a cylindrical metal cup that has been smoothed at the rim and measures 55 mm in internal diameter by 40 mm in depth.

With the cone securely held in its support, the cone is carefully lowered until it lightly touches the surface of the soil in the cup. The cone is then released and allowed to penetrate the soil for 5 seconds before being tested for depth of penetration (Fig. 2). The test is repeated until a consistent penetration value is attained, which is when the average of two values is within 0.5 mm of each other or three values are within 1.0 mm of each other. This entire process is repeated at least four times with the same soil sample while slowly increasing the water content, ensuring that penetration values fall within a 15 mm to 25mm range.

The recorded cone penetrometer values are plotted against the corresponding water content, and a straight line is drawn to best fit the data points. The liquid limit is determined as the water content at which the cone penetrates to a depth of 20 mm. The recorded cone penetrometer values are plotted against corresponding Casagrande values. Then a straight line is drawn to fit data points.

Fig. 2. Determination of liquid limit using cone penetrometer method

B. Data Analysis

Soil classification

Fig. 3 shows Particle size distribution (PSD) curves of five soil samples. Using PSD curves, 10% of passing (D10), 30% of passing (D30) and 60% of passing (D60) of each soil were determined and then coefficient of uniformity (Cu) and Coefficient of Curvature (Cc) were calculated using equations 1 and 2 listed below.

$$C_u = \frac{D_{60}}{D_{10}} \qquad (1)$$

$$C_c = \frac{(D_{30})^2}{D_{60} * D_{10}} \qquad (2)$$

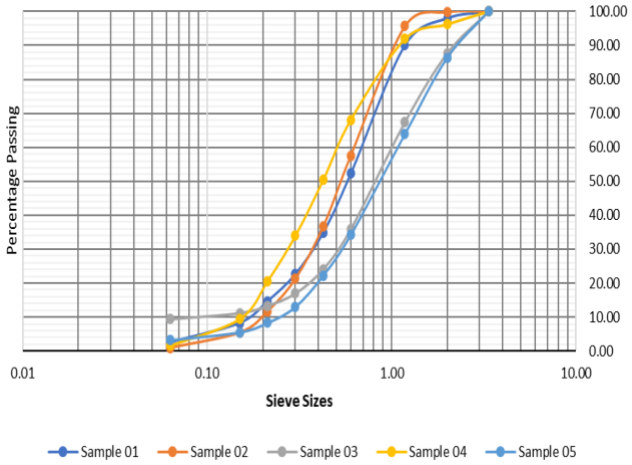

Figure 3: Particle size distribution of samples

As per the Unified Soil Classification System (USCS) all five samples are classified, and the results are shown in Tab. 1. Accordingly, all five samples are classified as poorly graded sands (SP).

TABLE 1. IMPORTANT VALUES OF SOIL CLASSIFICATION OF SAMPLES

	Sample 01	**Sample 02**	**Sample 03**	**Sample 04**	**Sample 05**
D10	0.18	0.2	0.078	0.16	0.26
D30	0.38	0.38	0.51	0.28	0.51
D60	0.7	0.61	1.02	0.51	1.02
Cu	3.8	3.05	13.07	3.18	3.92
Cc	1.14	1.18	3.27	0.96	0.98
Soil Type	SP	SP	SP-SC	SP	SP

Liquid limit analysis

The estimated liquid limit values for five samples using Casagrande method (LL_{CAS}) and cone penetrometer (LL_{CONE}) method are shown in Tab. 2.

Fig. 4 shows the comparison of liquid limit values estimated from both methods.

TABLE 2. LIQUID LIMIT VALUES FOR SOIL SAMPLES

Sample	**Soil type**	**LL_{CAS}**	**LL_{CONE}**
01	SP	19	21
02	SP	12	13
03	SP-SC	28	29

04	SP	17	19
05	SP	31	32

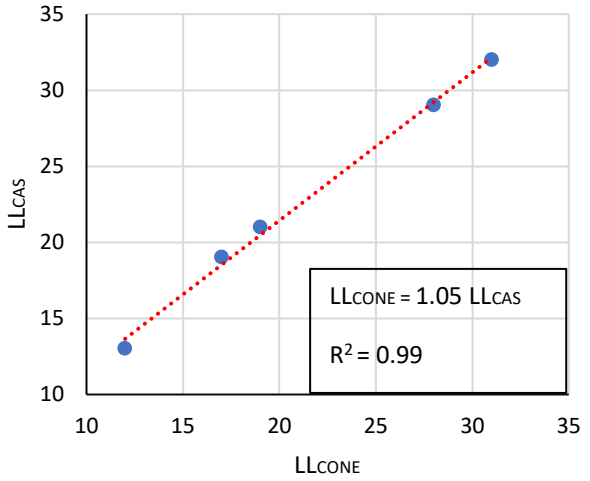

Fig. 4. Correlation of liquid limit values of cone penetrometer method and casagrande method

From Tab. 2, it is observed that LL estimated using cone penetrometer is slightly higher compared to the values taken from Csasagrande method. However, the variation range remains within 3–12 % limiting to the average deviation about to 5%. Therefore, it can be concluded that LL estimated from Cone penetrometer is also comparable to the values from Casagrande method to reasonable degree of accuracy.

Also in this study, equation 3 is proposed relating LL_{CAS} and LL_{CONE} as per the graph shown in Figure 4. Here, the relevant $R^2 = 0.99$ confirms the best matching of LL_{CAS} and LL_{CONE}.

$$\boldsymbol{LL_{CONE} = 1.05\, LL_{CAS}} \qquad (3)$$

III. Simplified Method for Estimating Optimum Moisture Content of Soil Compaction

A. *Experimental Procedure*

The optimum moisture content for soil compaction was determined using the same five samples that were previously discussed. Optimum moisture content and the highest dry density that can be attained with a certain compaction effort are the key findings of the standard Proctor compaction test. During the procedure, the link between the soil's density and moisture content will be discovered. The compaction effort measured in the field and the one intended for this lab test are similar.

As per ASTM D1557, 2.5kg rammer is dropped from 300mm to compact soil in the mould. Compaction was proceeded for three layers. The maximum dry density and their related optimum moisture content were found by mixing soil with various water contents to reach the desired dry density. The study aimed to investigate potential relationship between five soil types by plotting the predicted optimum moisture content values against relevant liquid limit values obtained using the cone penetrometer.

In this study, optimum moisture content values estimated for five soils were plotted against relevant liquid limit values obtained from cone penetrometer method for developing a possible relationship between them.

B. *Data Analysis*

Fig. 5 shows the proctor compaction curve developed for all five cases and from which optimum moisture content values for each case were determined.

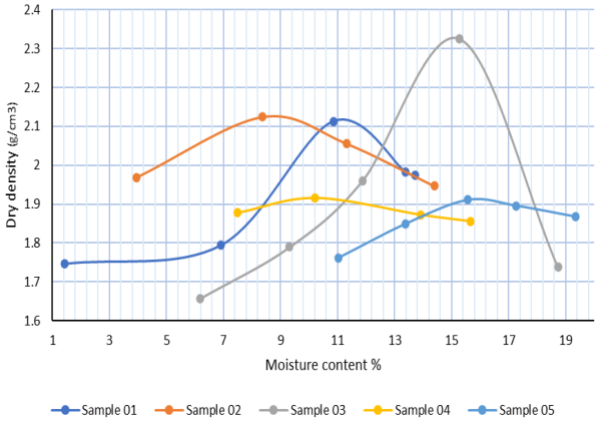

Fig. 5. Proctor curves of samples

The derived optimum moisture content values of five samples and corresponding liquid limit values obtained from cone penetrometer method are shown in Tab. 3.

TABLE 3. Optimum Moisture Content and Liquid Limit Values of Samples

SAMPLE	LL_{CONE}	OMC
01	21	11
02	13	09
04	19	10
05	32	16

The comparison of optimum moisture content values and corresponding liquid limit values are plotted in Fig. 6.

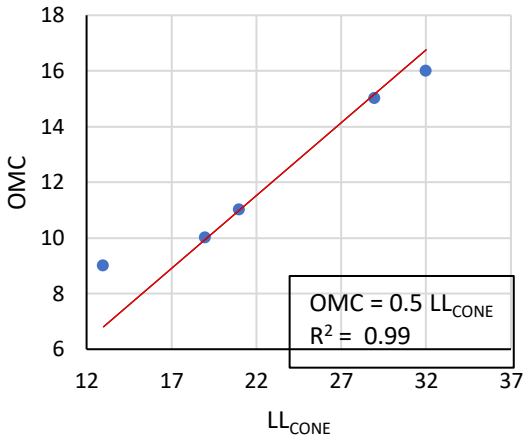

Fig. 6: Correlation between LL_{CONE} and OMC

As shown in Fig. 6, it is clearly shown that OMC relates well with the LL $_{CONE}$ to a good level of accuracy being the R^2 = 0.99. Equation 4. below shows the developed relationship from which OMC can be estimated just using the LL $_{CONE.}$

$$\boldsymbol{OMC = 0.5\, LL_{CONE}} \qquad (4)$$

IV. CONCLUSION

Based on performed experimental laboratory testing, the following conclusions can be finalized.

When the results were examined in relation to liquid limit estimation from Casagrande technique and cone penetrometer technique, it can be concluded that both methods provide approximate values reporting the variation range between limiting to the average variation only to 5%. Also, findings indicated that, overall, the Casagrande technique consistently yielded lower values compared to the cone penetrometer method. Additionally, a correlation between LL_{CAS} and LL_{CONE} has been introduced, as shown in equation 3. relating LL $_{CONE}$ and LL $_{CAS}$.

Even though previous researchers have pointed that LL_{CAS} and LL_{CONE} are not comparable, in this study we can conclude that LL_{CAS} and LL_{CONE} are comparable to good level of accuracy. As discussed above, the average variation limiting only to a 5% The authors believe that this degree of precision aligns with practical application in geotechnical engineering applications. Hence, the cone penetrometer emerges as a viable alternative for promptly, easily, and efficiently determining liquid limit with a reasonable level of accuracy.

In comparison with the Casagrande method, cone penetrometer method is easier, quicker, and simpler to perform.

Based on the data depicted in Figure 6, a correlation exists between LL_{CONE} and OMC. Consequently, it is feasible to derive a straightforward formula for estimating OMC based on LL_{cone} data for soil samples as shown in equation 4. Simply, it can be concluded that OMC is only a half of the liquid limit estimated from the cone penetrometer test. Further, in the case of unavailability of experimental data for LL $_{CAS}$, the authors suggest using equation 3 to estimate LL $_{CONE}$ using the LL $_{CAS}$ and then apply equation 4 to find out OMC.

In summary, from the proposed solutions above, optimum moisture content value can be determined just using liquid limit value obtained either Casagrande or cone penetrometer method without conducting standard Proctor compaction test. This facilitate much of the money, time, effort and material savings and is much useful for finding preliminary level approximation value of OMC very quickly.

However, in this study, all tested five samples are poorly graded sands and therefore, the direct applicability of proposed solutions is limiting to the same soil type (poorly graded sands). But authors suggest that the same procedure can be carried out to other soil types and there is possibility of generating similar relationship to estimate OMC using liquid limit values to a good level of accuracy.

FUTURE RECOMMENDATIONS

The similar relations can be developed furthermore to other soil types using the same procedure outlined above enabling a faster way of estimation OMC for any soil type just using liquid limit values.

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2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

Evaluation of Technical Feasibility and Optimum Mix Parameters for Recycled Asphalt Pavements in Sri Lanka

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***Abstract*—Recycled or reclaimed asphalt pavement (RAP) utilization has increased in the pavement sector as a result of the depleting availability of virgin materials, rising production costs, and a lack of landfill space to dispose of old materials in many countries. Here, when a road needs to be paved, the old pavement is milled from the road and then subsequently crushed, screened, and reincorporated into a fresh asphalt mix. In Sri Lanka, there has been rapid improvement in the road engineering sector over the past few years. However, the use of recycled asphalt pavements has not been seen either in repaving or constructing new roads in Sri Lanka. This research was initiated to assess the suitability of RAP materials in Sri Lanka by Marshall Mix Design and to evaluate their technical feasibility. In this study, different percentages of RAP were mixed with virgin binder and virgin aggregates to perform the Marshall Mix Design, and the results were compared with the performance criteria of a control mix specimen (0% RAP). The existing RAP binder content was determined using the centrifuge extraction method. The results of Marshall stability, Marshall flow, Air voids (V_a), and Voids in mineral aggregates (VMA) were meticulously analyzed for each percentage of RAP mix specimen to determine the optimum mix parameters for RAP.**

***Keywords*—Recycled asphalt pavement (RAP), marshall mix design, road engineering, optimum mix parameters**

I. INTRODUCTION

Hot Mix Asphalt (HMA) has been extensively used as a pavement mix in road construction in Sri Lanka, as most of the urban and considerable portions of the rural road networks are bituminous pavements. Typically, for HMA production, aggregates are obtained through rock blasting, and these natural resources are depleting, resulting in increased costs alongside the rising production costs of virgin asphalt binder. Consequently, there is an urgent need to identify suitable and cost-effective materials for road paving in Sri Lanka. Conventionally, in Sri Lanka, when a road needs to be repaved, a new HMA mixture is applied over the degraded surface or the deteriorated surface is milled out and disposed of without further use. In the RAP method, the damaged surface is milled out, then crushed, screened, and reincorporated into a fresh asphalt mix, which is subsequently applied as a recycled asphalt mixture.

To date, studies have been conducted on the use of RAP in HMA mixtures in various countries. Because of its unique qualities, RAP serves as a practical and cost-effective substitute for virgin aggregates, consequently reducing the demand for new virgin aggregates. Additionally, the utilization of RAP leads to decreased reliance on expensive new asphalt binders in asphalt paving mixtures, further enhancing its benefits [1]. It was found that the aged asphalt binder in RAP coats the RAP aggregate particles in a stiffer layer as opposed to a mixture with 100% virgin asphalt, and the addition of RAP to HMA mixtures has the advantageous result of creating a good layered structure to improve the performance of the pavement [2]. Some previous research findings have suggested that asphalt mixtures incorporating RAP can exhibit equivalent or even superior structural performance compared to virgin asphalt concrete, provided they are designed appropriately with the right recycled asphalt concrete design and a suitable RAP percentage [3].

To avoid detrimental effects on the mix properties, most road authorities allow no more than 30% of RAP to be used in hot mix asphalt (wearing course). This is mainly because of RAP's general stiffness, largely resulting from oxidative hardening and other aging processes it endures over its period of exposure to the environment during its service life [4].

A method for determining the necessary mix design properties (such as stability, flow, and air void content) for the Marshall mix design method is provided in the Asphalt Institute's manual on mix design methods for asphalt concrete [5]. After conducting mix design testing for the asphalt mixes including 6 aggregate combinations with RAP levels of 0% (control), 5%, 10%, 15%, 20%, and 25% by standard procedures to meet the relevant mix design criteria, the optimum mix parameters for RAP mixtures will be established. The objective of this study is to recommend guidelines and best practices for the incorporation of RAP in hot mix asphalt to achieve sustainable and high-performance road pavements in Sri Lanka by investigating the impact of varying RAP percentages on the volumetric properties, stability, and flow characteristics of hot mix asphalt.

II. METHODOLGY

For this study, the Marshall method was used as it is the widely accepted method for designing asphalt mixes. This enables to stress a complete sample rather than just a portion of it for stability and flow. Fig. 1. Shows the experimental methodology used in this study.

A. RAP Materials and Virgin Aggregates

The source of the RAP material was a road rehabilitation project near Trincomalee, where the upper layer of the existing pavement was removed. Then the collected RAP materials were hammered and crushed. Using the centrifuge extraction method, the existing bitumen percentage of RAP materials was determined as per AASHTO T164-06 [6]. Virgin aggregates were obtained from a crusher plant located near Trincomalee and Sieve Analysis was performed for both virgin and RAP aggregates according to AASHTO T27-99 [7] to grade the aggregates for Wearing Course Type 2 as given in the ICTAD (Institute for Construction Training and Development) specifications [8]. To determine the engineering properties of RAP aggregates, Aggregate Impact Value (AIV), Los Angeles Abrasion Value (LAAV), Flakiness Index test, Bulk Specific Gravity test (G_{sb}) and Water Absorption test were conducted in accordance with BS 812-112: 1990(1990) [9], AASHTO T96-02(2002) [10], BS 812: part 105.1:1989(1990) [11] and AASHTO T85–91(2000) [12] respectively. These obtained properties were compared with the virgin aggregates to evaluate whether they are in conformity with the specified range of fresh aggregates.

B. Virgin Binder

Bitumen penetration grade 60/70 was selected for this research because it is the grade of bitumen commonly used in road construction in Sri Lanka.

C. Marshall Testing

After collecting virgin aggregates, RAP materials, and bitumen binder, the Marshall test was conducted to a series of trial aggregate-asphalt binder mixes. The bitumen content was varied in 0.5% increments to determine the optimum binder content (OBC). The range of bitumen content percentages tested included 4%, 4.5%, 5%, 5.5%, and 6%, in accordance with ICTAD specifications. A total of 15 specimens were prepared, with 3 samples allocated for each blend. Then the OBC was determined by evaluating the Marshall stability, Marshall flow, and volumetric properties of each blend.

After determining the OBC value, that value was used to make a controlled sample (0% RAP) and 5 other RAP samples as well. For this, 3 samples were prepared for each RAP content. When preparing the RAP specimens, the existing bitumen content was disregarded for the 5%, 10%, and 15% mixes. For the 20% and 25% RAP mixes, half of the existing binder content was considered [13], and virgin binder was added to reach the required amount to achieve OBC. These RAP samples were with 5%, 10%, 15%, 20%, and 25% of RAP. The obtained results for Marshall stability, Marshall flow, and volumetric properties of the control sample and RAP samples were compared to the values given in the ICTAD specifications for high-traffic, flexible pavements.

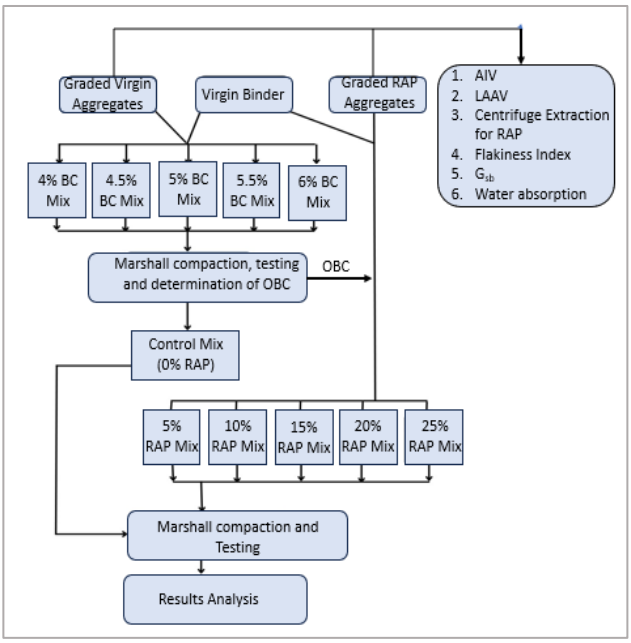

Fig. 1. Experimental methodology flow chart

TABLE I. PHYSICAL PROPERTIES OF VIRGIN AND RAP AGGREGATES

Aggregate Properties	Virgin Aggregates	RAP Aggregates	ICTAD Requirements
AIV (%)	14.39	6.2	<30
LAAV (%)	39.1	38.5	<40
Flakiness Index Value (%)	21.22	10.12	<35
G_{sb}	2.707	2.361	<2.75
Water Absorption (%)	0.37	0.30	<2.0

III. RESULTS AND DISCUSSION

A. Physical Properties of Virgin and RAP Aggregates

The results of AIV, LAAV, Flakiness Index test, Water absorption, and Bulk Specific Gravity for virgin aggregates and RAP aggregates are shown in Table I.

The toughness of the specimens was measured by the AIV test and the obtained values for both virgin and RAP aggregates were within the ICTAD acceptable range. The lower value shown by the RAP sample may be due to the presence of an aged binder layer which tends to develop a more resilient and cohesive matrix over time. Abrasion values were also within the ICTAD required range for both specimen types. The higher value shown by the RAP sample may also be due to the presence of an aged binder layer which causes brittleness, and ultimately leads to increased abrasion and

wear of the aggregate particles. Both RAP and virgin aggregates displayed an acceptable flakiness index.

G_{sb} value for RAP showed a lower value than virgin aggregates. This may be because of the brittle and less cohesive nature of the aged binder which could create additional voids within the RAP aggregates. The water absorption of RAP aggregates was also lower than that of virgin aggregates. This may be attributed to the coating of RAP aggregates with asphalt binder, which could aid in covering the existing voids of the aggregate and reducing the water absorption.

B. Existing Bitumen Percentage of RAP

From the mass difference of dried aggregate sample before the test and aggregate sample after the centrifuge extraction, existing bitumen percentage of RAP was calculated. The resulting value was 4.19%.

C. Optimum Binder Content (OBC)

The OBC for the control and RAP mixes were determined by the Asphalt Institute procedure from the individual plots of, air voids, unit weight, stability, and flow versus percent binder content. Corresponding binder content values for achieving 4% of air voids, maximum unit weight, and maximum stability were considered. The average value was taken as the OBC, and the target OBC was verified to ensure that the VMA and flow requirements were met. The obtained binder content value was 4.8%.

D. Marshall Properties Analysis

Table II shows the results from the Marshall tests on control and RAP specimens with the ICTAD requirements. It was revealed that all the values obtained for RAP samples lie between the ICTAD specified range. Fig. 2, Fig. 3, Fig. 4, and Fig.5 are comparison diagrams of mixtures before and after the addition of RAP based on Marshall stability, Marshall flow, V_a, and VMA respectively.

TABLE II. MARSHALL AND VOLUMETRIC PROPERTIES FOR DIFFERENT RAP CONTENTS

Marshall Property	**0% RAP**	**5% RAP**	**10% RAP**	**15% RAP**	**20% RAP**	**25% RAP**	**ICTAD Requirements**
Stability (kN)	12.73	12.73	12.75	14.89	13.82	13.28	≥ 8
Flow (0.25mm)	9.6	9.2	11.6	11.6	12.4	12.8	8 - 16
V_a (%)	3.98	3.95	3.9	3.88	3.73	3.59	3 - 5
VMA (%)	14.94	15.39	15.84	16.31	16.66	17.03	≥ 13

According to Fig. 2, the stability value increases up to 15% RAP and then tends to decrease with the increasing RAP content. It was revealed that the addition of RAP increased the stability of the control mix and the highest increase was at the 15% RAP, which was 16.96%.

Based on Fig. 3, it was found that the flow value tends to increase with the increasing RAP content. 25% RAP specimen shows the highest flow value and increasing flow value will make the specimens more plastic and easier to deform. The reason for the increasing flow value may be due to the increasing aged binder content which shows lower cohesive properties than the virgin binder. This can make the mixtures with high RAP percentages more prone to deformation or flow.

Fig. 4 showed that the V_a value tends to decrease with the increasing RAP content. Increasing RAP content decreases the virgin binder content which could lead to more compacted mixtures with fewer air voids.

Fig. 5 revealed that VMA value tends to increase with the increasing RAP content. This could be because the aged binder may not coat the aggregates as effectively as virgin binder. This could create void spaces within the mineral aggregates.

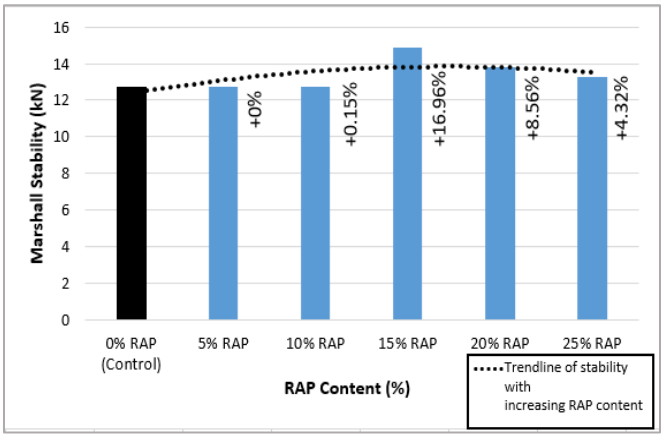

Fig. 2. Variation of Marshall stability with RAP content

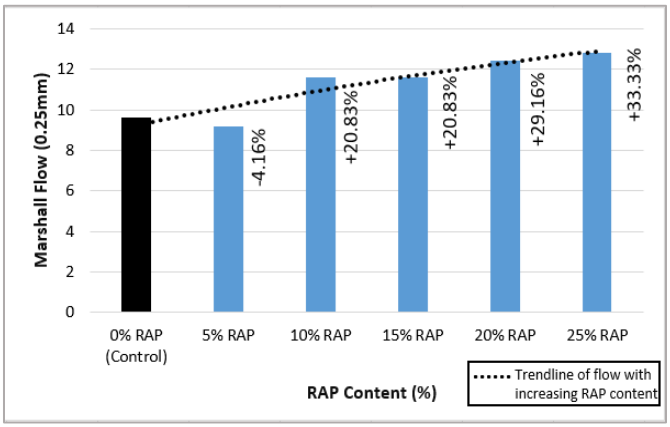

Fig. 3. Variation of Marshall flow with RAP content

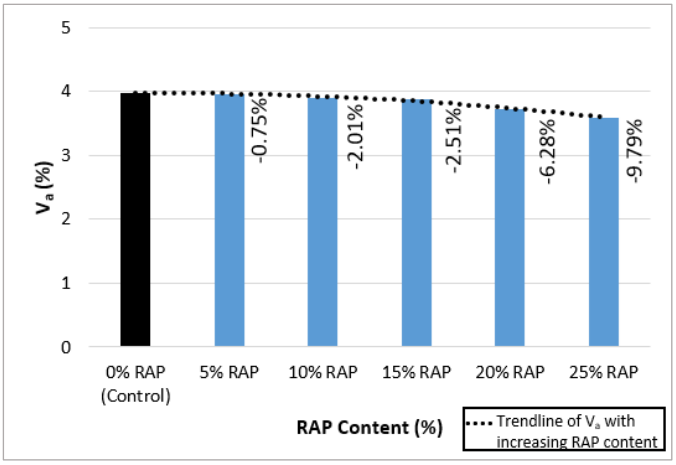

Fig. 4. Variation of V_a with RAP content

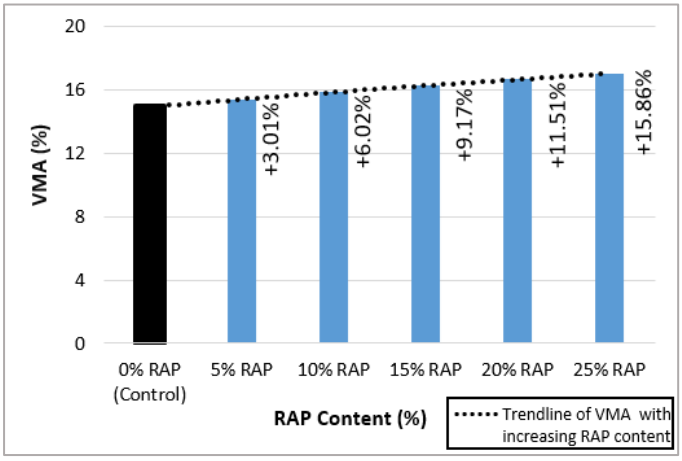

Fig. 5. Variation of VMA with RAP content

IV. CONCLUSIONS

The following can be concluded from this study:

1. Laboratory investigation of the physical properties of aggregates showed that both RAP and virgin aggregates used for this study complied with the requirements of ICTAD.
2. HMA mixtures including RAP can show higher Marshall Stability values than conventional (0% RAP) HMA mixtures.
3. The addition of RAP increases the susceptibility of HMA mixtures to deformation but remains within the specified ICTAD range.
4. Increasing RAP percentage affects the volumetric properties of HMA mixtures by decreasing V_a and increasing VMA values, possibly due to the presence of aged binder. However, all values remain within the specified ICTAD range.

Most importantly, all Marshall and volumetric properties even at the highest RAP content of 25%, fall within the specified ICTAD requirements. However, it can be concluded that beyond 15% RAP, factors such as inadequate virgin binder content and increased amount of aged asphalt binder can start to outweigh the benefits of RAP incorporation. Based on the technical analysis of Marshall properties, a 15% RAP percentage can be used as an optimal RAP content for incorporation into HMA mixtures in Sri Lanka, since it offers a balanced approach by providing a substantial high amount of stability value, moderate flow value and with the slight reduction of air voids it provides an improved density condition.

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2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

Displacement Demand Estimation of an Elevated Rectangular Reinforced Concrete Water Tank Using Nonlinear Time History Analysis: A Case Study

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***Abstract*—This paper presents a research study aimed at understanding the displacement demand and the dynamic behavior of an elevated reinforced concrete rectangular water tank subjected to moderate and strong seismic events. The water tank was designed to resist gravity and wind loads and was subjected to ground acceleration records obtained from actual seismic events. The tank was analyzed in both empty and fully filled states using nonlinear time history analysis by providing eleven ground acceleration records as the dynamic lateral force. The results were then examined in terms of displacement demand, base shear, nonlinear behavior, and resonance of the tank. The study revealed that the displacement demand of a structure subjected to a seismic event is not solely determined by a single factor, but rather it is influenced by a combination of factors, including peak ground acceleration (PGA), duration, and the earthquake magnitude. Furthermore, the absence of plastic hinge formation under seismic events with a PGA around 0.1g indicates that, despite this type of water tanks in Sri Lanka not being explicitly designed to withstand seismic forces, they exhibit a robust resistance to earthquakes of this magnitude. As a result, it can be concluded that such tanks are unlikely to fail during seismic events of this magnitude.**

Keywords—Time history analysis, displacement demand, dynamic behavior, plastic hinges, ground acceleration

I. INTRODUCTION

Elevated water tanks serve a vital function within water storage and distribution systems, catering to the specific needs of various regions and communities. These tanks are available in a diverse range of shapes, sizes, and materials, designed to suit their intended purpose and regional requirements. Rectangular reinforced concrete tanks are a popular choice in many regions worldwide due to their space efficiency, low construction cost, ease of construction and maintenance. Various staging types are employed to support elevated RC water tanks, with frame staging being commonly used. Kumbhar et al. [1] stated that these elevated water tanks supported by the reinforced concrete staging are classified as inverted pendulum structures as most of the mass is concentrated on the top of the tank staging.

Seismic events generate ground accelerations and any structure that experiences those will gradually deform until it achieves its maximum displacement. This maximum deformation is known as the displacement demand of the structure, and it is a critical factor in determining the structural stability and safety of structures subjected to dynamic loadings. There are four primary approaches to analyze structures in practice and time history analysis which is a type of dynamic analysis is one of the best suited for studying the behavior and the displacement demand of structures subjected to dynamic loadings, considering material yielding, large deformations, and nonlinearities. It provides a step-by-step evaluation of a structure's dynamic behavior, using modal or direct integration methods to solve dynamic equilibrium equations, generally referred to as equations of motion. Soroushnia et al. [2] have studied and analyzed a sample of a reinforced concrete elevated water tank, with 900 cubic meters under one earthquake record using dynamic time history analysis. For three cases of completely filled, half filled, and empty tanks time history analysis was performed and failure modes and damages to structures were evaluated.

Currently, the US National Earthquake Information Center tracks roughly 20,000 earthquakes annually, or about 55 per day, around the world. Long-term records (dating back to around 1900) predict that there will typically be 16 significant earthquakes per year. Therefore, it is imperative to ensure that critical structures, such as water tanks, are functional following seismic events. Given that Sri Lanka is not located in an area prone to earthquakes, the infrastructure is typically not designed to withstand seismic forces. Seneviratne et al. [3] had analyzed over 300 records of earthquakes around Sri Lanka and found that the Mannar rift zone and Comorin ridge is the critical zone of influence capable of generating a seismic event of magnitude 6.9 at a 475-year return period at a depth of 10-15 km below the sea level. As such, seismicity in Sri Lanka can no longer be ignored. Uduweriya et al. [4] found that the Peak Ground Acceleration (PGA) is highest in the west coastal zone within a range of 0.05 to 0.1 g, with an approximate PGA value of 0.1 g in Colombo, using Probabilistic Seismic Hazard Assessment (PSHA) that considers seismic activities in the surrounding region.

Given the paramount significance of seismic analysis, it is imperative to investigate the behavior of structures exposed to seismic forces and to incorporate seismic design considerations into the structure if any weaknesses are uncovered. In order to improve the construction and design of these structures, it is essential to have a comprehensive understanding of the behavior of displacement demand. This paper will focus on the changes in displacement demand and the dynamic behavior of an elevated reinforced concrete water tank with respect to different ground acceleration records in the context of moderate and strong seismic events, utilizing nonlinear time history analysis.

II. METHODOLOGY

In this study, an elevated reinforced concrete water tank has been designed to resist the effects of gravity and wind loads. The designed structure is then subjected to nonlinear time history analysis to estimate the displacement demand that may result from ground accelerations caused by seismic events. The tank is analyzed under both empty and fully filled conditions, and the results are evaluated in terms of displacement demand, base shear, nonlinear behavior, and resonance of the tank. Etabs Ultimate [5] is primarily employed for structural design as it offers specialized tools for designing shear wall reinforcement, an option not available in SAP2000 [6]. Subsequently, the designed structure is modelled in SAP2000 for conducting time history analysis. This choice is influenced by SAP2000's user-friendly interface, which is advantageous for performing complex time history analyses.

A. Design of the Elevated Rectangular Water Tank

The elevated rectangular tank has been designed in accordance with its Ultimate Limit State (ULS), and Serviceability Limit State (SLS) in compliance with Eurocodes [7, 8]. However, seismic forces were not considered during the design process. The design requirements, material properties and the designed section sizes are outlined in Tab. 1 to 3.

TABLE I. DESIGN REQUIREMENTS

Design Requirements	Value
Capacity	300 m^3
Width of the Tank	7 m
Length of the Tank	10 m
Height of the Tank	5 m
Staging Height	12 m

TABLE II. MATERIAL PROPERTIES AND DESIGN PARAMETERS

Material Properties & Design Parameters	Value
Concrete Class	30/37
Concrete - Density	25 kN/m^3
Concrete - Modulus of Elasticity	33 GPa
Steel Reinforcement - Characteristic Yield Strength	500 N/mm^2
Steel Reinforcement - Density	78.5kN/m^3
Steel - Modulus of Elasticity	200 GPa
Water Tightness Class	1
Basic Wind Speed	22 ms^{-1}
Exposure Condition	XC3/4

TABLE III. MEMBER SIZES AND OTHER DESIGN INFORMATION

Description	Dimensions (mm)
Column (C1)	350 x 350
Main Beam (B1)	400 x 350
Bracing Beam (BB1)	400 x 350
Top Slab (TS)	150
Bottom Slab (BS)	300
Shear Wall (SW1)	350
Clear Cover	40

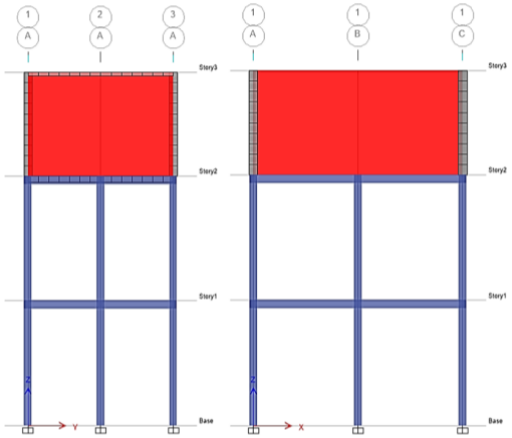

Fig. 1. Elevation views of the designed water tank

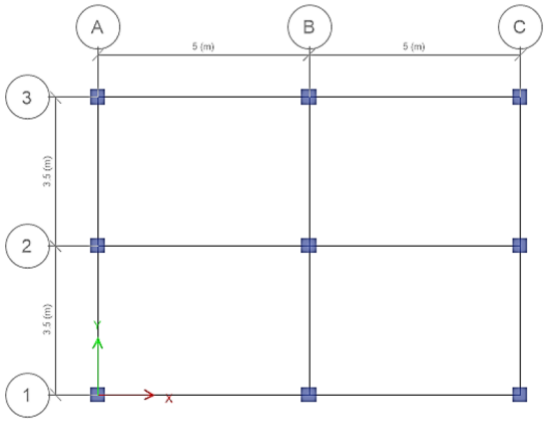

Fig. 2. Column layout of the water tank

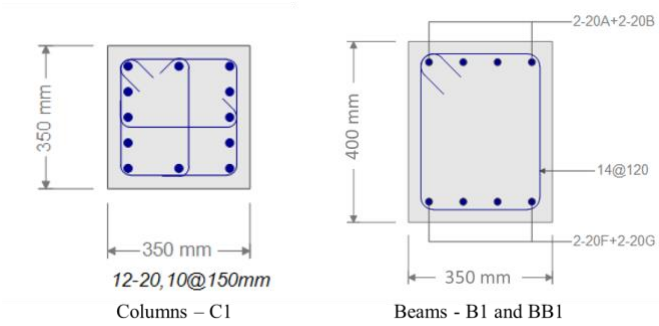

Fig. 3. Reinforcement details of the staging

B. Finite Element Model

The geometry of the tank and reinforcement details are shown in Fig. 1, 2 and 3. The finite element models of the structures were developed utilizing the SAP2000 program, as shown in Fig. 4. These models accurately represent the physical properties and geometry of the structure, including its materials, connections, and boundary conditions. The tank

was modelled with the assumption that it is fixed at the base. For the purpose of the study, both the tank empty and full conditions were considered. A total of 22 combinations were studied for the tank under eleven different earthquake ground motions.

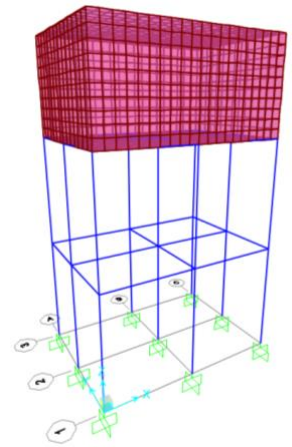

Fig. 4. Finite element model of the water tank

When the tank is fully filled, the mass is evenly distributed along the perimeter of the tank at the mid-level (14.5 m from the ground and 2.5 m from the tank base). The staging has been modelled with plastic hinges to accommodate for the non-linearity of the structure under both empty and full conditions, as depicted in Fig. 5. The default Moment (M3) hinges and axial load and moment (P-M2-M3) hinges available in SAP2000 were assigned for beams and columns respectively. The moment-rotation relationships and acceptance criteria for hinge performance levels were sourced from ATC 40 (Applied Technology Council) [9] and FEMA 356 guidelines (Federal Emergency Management Agency) [10]. Hinges were allocated at 0.05 and 0.95 of the relative distance along each frame element [11].

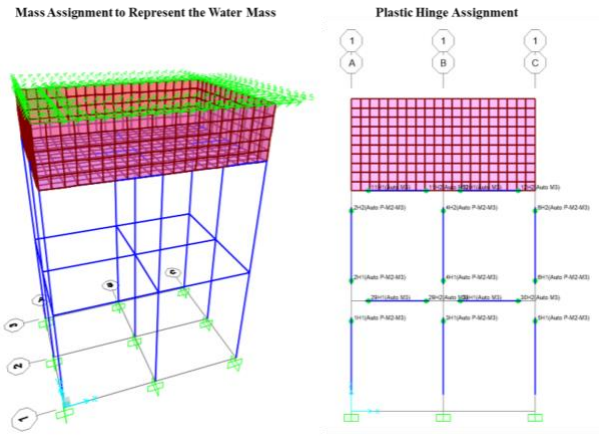

Fig. 5. Water mass and plastic hinge assignment

The natural frequencies of the first two modes of both empty and fully filled water tank were calculated using (1). The stiffness (k) was derived from the gradient of the pushover curves obtained through pushover analyses of the finite element model. The mass (m) was determined by considering the concrete and water masses. Tab. 4 presents the resulting values. The validity of the finite element model was confirmed by comparing the first two modes natural frequencies computed using (1) with those obtained by modal analysis of the finite element model as shown in section III. D.

$$\omega_n = (1/2\pi)\,(\sqrt{k/m}) \quad (1)$$

TABLE IV. STIFFNESS, MASS AND NATURAL FREQUENCIES

Description	Stiffness (N/m)	Mass (kg)	Natural Frequency (Hz)
Empty Tank – Mode 1	5888828.5	298912.9	0.71
Empty Tank – Mode 2	6218281.0	298912.9	0.73
Fully Filled Tank – Mode 1	5618511.0	604417.4	0.49
Fully Filled Tank – Mode 2	5931836.4	604417.4	0.50

C. *Selection of Ground Motions*

Seismic ground motion records, also known as accelerograms or seismograms, are digital illustrations that depict the ground motion ensuing from an earthquake. These records provide precise information about the time-history of ground accelerations, velocities, and displacements during an earthquake. These accelerations serve as the input data for time-history analysis. The ground motions were sourced from the PEER Database [12] and were selected based on the following criteria. Six records of 0.1g PGA were chosen to conform to the Sri Lankan conditions, and five records with a PGA greater than 0.1 were selected from moderate and strong seismic events.

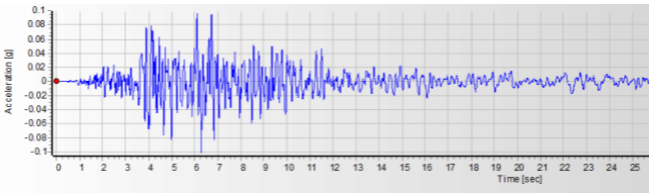

Fig. 6. Sample ground acceleration record (*M3-Westmoreland Earthquake*)

The ground acceleration records from moderate earthquakes with a magnitude between 5.0 and 5.9, and strong earthquakes with a magnitude between 6.0 and 6.9 were selected and the selected earthquakes are listed in Tab. 5 in ascending order based on their PGA. A sample acceleration record is shown in Fig. 6. The magnitude of each earthquake is expressed in the moment magnitude scale.

TABLE V. SELECTED GROUND MOTION RECORDS

EQ ID	Name	Magnitude	Duration (s)	PGA (g)
M1	Mammoth Lakes-04	5.70	40.00	0.098
M2	Anza (Horse Canyon)-01	5.19	10.31	0.099
M3	Westmorland	5.90	40.00	0.101
M4	Coyote Lake	5.74	26.83	0.102
M5	Coalinga-04	5.18	19.01	0.105
M6	Whittier Narrows-02	6.19	21.99	0.113

S1	Parkfield	6.53	26.20	0.248
S2	Imperial Valley-06	6.61	37.84	0.277
S3	San Fernando	6.06	36.68	0.382
S4	Mammoth Lakes-01	5.77	29.99	0.430
M7	Coalinga-05	6.19	21.73	0.575

D. Time History Analysis

Nonlinear time history analysis is a numerical approach employed to simulate the dynamic response of a structure under seismic or other dynamic loads. Unlike linear analysis, which fails to account for the nonlinear behavior of materials and components, this method provides a more accurate portrayal of a structure's deformation and response to realistic, nonlinear conditions such as material yielding, large displacements, and plastic hinge formation. In this research, the direct integration method is chosen as the solution type when conducting the time history analysis. The Hilber-Hughes-Taylor (HHT) method has been selected as the numerical integration technique for conducting time history analysis as it is effective when dealing with significant variations of stiffness and mass matrices during the analysis, such as in the presence of nonlinearities. Also, this method is proven to yield more stable base shear results compared to Newmark, and Chung & Hulbert Method [13]. The analysis was conducted incorporating P-delta nonlinearity, and assuming a damping of 5%.

III. Results and Disscussion

The nonlinear time history analysis is performed on the both the empty and fully filled tanks. The results were documented and discussed in terms of displacement demand, base shear, frequency content and plastic hinge formation.

A. Displacement Demand

The displacement demand of the structure is the maximum expected displacement that the structure will experience during a given seismic event. Displacement demand comparative to the structure's capacity determines whether it can safely withstand the expected seismic forces and deformations. If the displacement demand exceeds the capacity, design modifications may be necessary to improve the structure's seismic performance, such as adding additional bracing or dampers, strengthening components, or altering the structural system.

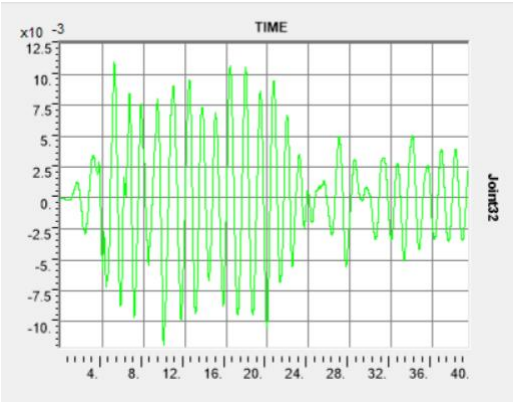

Fig. 7. Sample Displacement Plot Function. (*M3-Westmoreland Earthquake*)

The maximum displacement recorded by considering a node (node no. 32) located in the roof of the tank, under empty and fully filled conditions for each earthquake is shown in Tab. 6. The maximum value is taken from the displacement plot function, as shown in Fig. 7. When evaluating the empty state, the maximum displacement demand is attained for the earthquake S4, where the PGA is 0.43g and the duration is 29.99sec. Conversely, the minimum displacement demand is attained for the earthquake M2, where the PGA is 0.099g and the duration is 10.31sec. Regarding the fully filled state, the minimum displacement demand is attained for the earthquake M2, similar to the tank empty condition, but the maximum displacement demand is attained for the earthquake M7, where the PGA is 0.575g and the duration is 21.73sec. Additionally, it is observed that the displacement demand of the empty tank, in comparison to the fully filled tank, is generally smaller, except in three instances. These instances include the earthquakes M1-Mammoth Lakes-04, M4- Coyote Lake, and S4-Mammoth Lakes-01.

TABLE VI. Maximum Roof Displacement

EQ ID	Displacement Demand (mm)	
	Empty	***Fully Filled***
M1	17.88	17.44
M2	1.951	4.243
M3	11.89	21.32
M4	13.08	10.98
M5	6.549	6.674
M6	17.52	15.46
S1	32.8	42.71
S2	44.66	50.59
S3	27.12	30.65
S4	68.21	50.97
M7	56.88	80.15

Fig. 8 and Fig. 9 illustrate the variation of displacement demand with PGA and Earthquake duration. Note that the PGA and duration axes are not scaled proportionally.

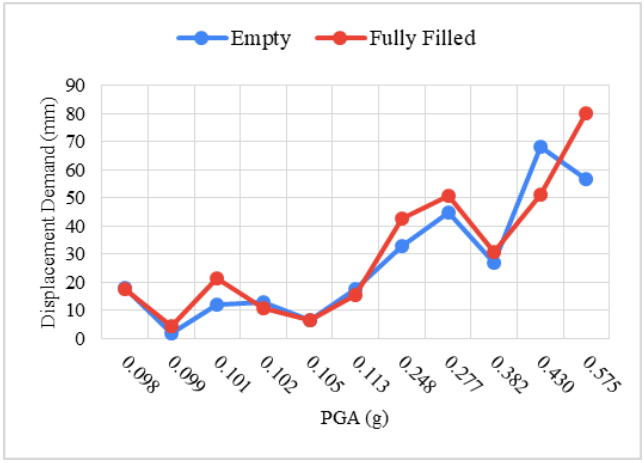

Fig. 8. Displacement demand variation with PGA

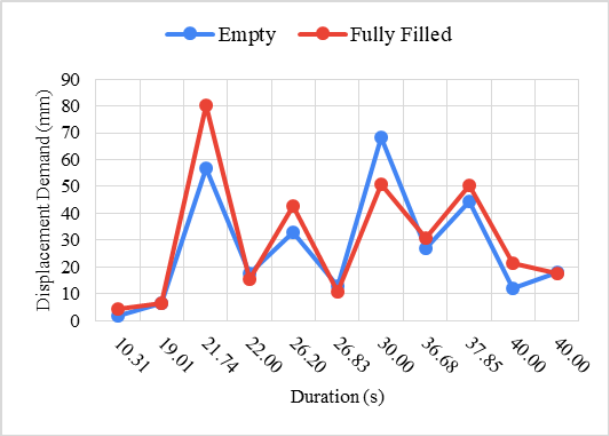

Fig. 9. Displacement demand variation with earthquake duration

It is observed that a direct relationship cannot be obtained for the displacement demand by considering PGA, magnitude, or duration individually.

B. *Base Shear*

The base shear of a structure subjected to an earthquake is the total lateral (horizontal) force or shear that is transmitted to the foundation of the building due to the seismic ground motion. The base shear is then distributed throughout the structure through lateral load-resisting elements like shear walls, moment frames, or bracing systems to ensure that the building can withstand the lateral forces and minimize damage. Accurate determination of the base shear is crucial in seismic design to ensure the safety of occupants and the structural integrity of the building during an earthquake.

Tab. 7 shows the maximum base shear values of all the cases considered. When evaluating the empty state of the tank, the maximum base shear was attained for the earthquake S4, while the minimum base shear was attained for the earthquake M2. Conversely, in the fully filled state, the minimum base shear was attained for the earthquake M2, similar to the tank empty condition, but the maximum base shear was attained for the earthquake M7. It was observed that the base shear increases in response to an increase in displacement demand unless the duration and PGA of the earthquake undergo significant variations.

TABLE VII. ABSOLUTE BASE SHEAR

EQ ID	Absolute Base Shear (kN)	
	Empty	***Fully Filled***
M1	99.41	89.01
M2	11.49	23.02
M3	65.66	115.29
M4	63.82	58.89
M5	29.18	29.93
M6	100.22	90.11
S1	155.00	180.05
S2	188.95	208.95
S3	166.21	155.94
S4	237.11	206.57
M7	209.38	257.91

C. *Plastic Hinge Formation*

Plastic hinges in structures are regions where significant plastic deformation or yielding occurs when the structure is subjected to loads, particularly during extreme events like earthquakes or strong winds. Plastic hinges are assigned to model these inelastic deformations accurately and it allows for the realistic representation of yielding and energy dissipation.

Based on the selected earthquakes, the formation of plastic hinges commenced when the PGA exceeded 0.105g. Tab. 8 includes the instance of forming plastic hinges. As shown in the table, the structure exhibited nonlinear behavior for earthquakes S1 to S4 and M7. Conversely, when the PGA was approximately 0.1g, the structure displayed linear behavior, resulting in the absence of plastic hinge formation. Fig. 10 shows the locations of plastic hinges.

TABLE VIII. PLASTIC HINGE FOMARTION

EQ ID	Hinge Formation Start Time (s)	
	Empty	***Fully Filled***
M1 to M6	Hinges aren't formed	Hinges aren't formed
S1	2.150	1.710
S2	5.815	5.900
S3	2.590	2.600
S4	5.655	8.500
M7	4.170	4.220

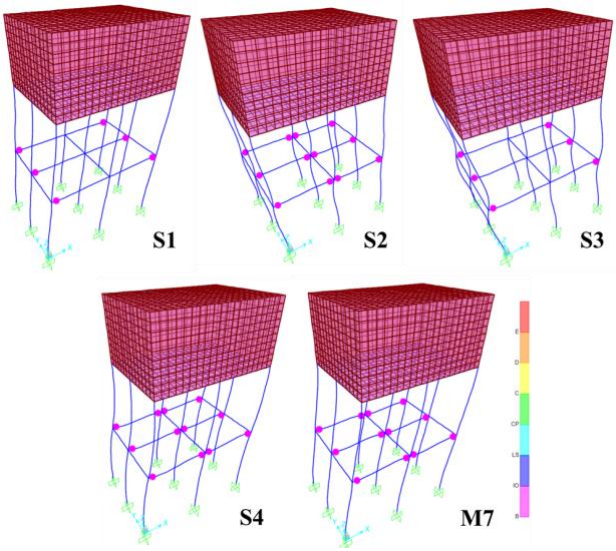

Fig. 10. Plastic hinge formation

D. *Natural Frequencies and Resonance*

The natural frequency of a structure is a fundamental property that characterizes its dynamic behavior. It represents the frequency at which a structure will naturally vibrate or oscillate when subjected to an external force or disturbance and then released. The natural frequency is primarily determined by the structure's mass and stiffness.

Modal analysis can be used to determine the natural frequencies and mode shapes of a structure. Tab. 9 highlights the natural frequencies corresponding to the first ten modes. It is observed that the natural frequency of the fully filled tank is always lower than the corresponding natural frequency of the empty tank. Determination of natural frequencies is essential for ensuring that the structure doesn't experience resonance, which can lead to structural damage or instability.

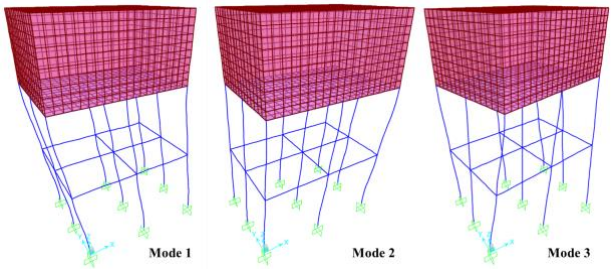

Fig. 11. First three mode shapes of the empty tank

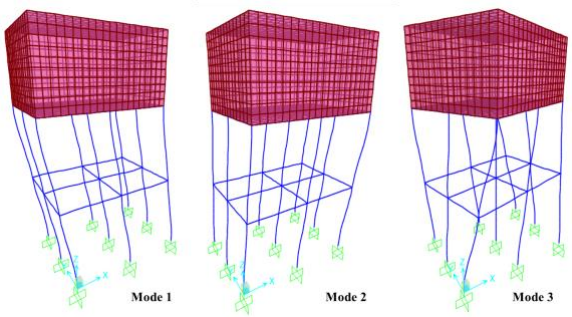

Fig. 12. First three mode shapes of the fully filled tank

TABLE IX. NATURAL FREQUENCIES OF THE TANK

Mode No.	Natural Frequency (Hz)	
	Empty	*Fully Filled*
1	0.71	0.49
2	0.73	0.50
3	0.88	0.57
4	4.57	4.53
5	4.59	4.54
6	5.05	4.99
7	8.56	8.56
8	9.20	9.20
9	13.02	12.70
10	13.64	13.64

Fourier analysis is utilized to analyze the individual frequencies of an earthquake by decomposing the ground motion into its constituent frequency components. In order to assess the resonance effect, the dominant Fourier frequencies of individual earthquakes can be compared with the natural frequencies of the structure. The dominant frequencies of the selected earthquakes obtained using the Seismosignal software [14] are recorded in Tab. 10. The first three mode shapes of empty and fully filled tanks are shown in Fig. 11 and 12, respectively. Frequency spectrum of Coyote Lake earthquake is shown in Fig. 13 as a representative case.

It was observed that the dominant frequencies of M1, M4, and S4 earthquakes correspond with the natural frequencies of the first several modes of the empty tank. Specifically, the frequency of 0.98 Hz in M1 nearly matches with the natural frequency of 0.88 Hz, while the frequency of 5.05 Hz in M4 corresponds with a natural frequency of 5.05 Hz. Additionally, the frequency of 4.57 Hz in S4 corresponds with a natural frequency of 4.57 Hz. Therefore, the maximum displacement demands obtained from the analyses contain the effects of resonance.

TABLE X. FREQUENCY CONTENT OF THE EARTHQUAKES

EQ ID	Dominant Frequencies (Hz)				
	1	*2*	*3*	*4*	*5*
M1	0.98	1.37	2.10	2.98	3.83
M2	2.83	6.54	11.91	12.79	13.62
M3	1.68	4.08	4.25	4.96	6.01
M4	1.20	1.61	2.98	4.42	5.05
M5	1.61	2.10	2.78	3.71	6.88
M6	1.15	1.42	1.64	1.78	2.12
S1	1.03	1.42	1.56	2.10	3.71
S2	1.00	1.25	1.34	1.86	2.10
S3	4.13	4.44	5.52	5.76	6.40
S4	1.34	1.83	2.42	3.34	4.57
M7	1.17	1.44	1.64	2.37	4.13

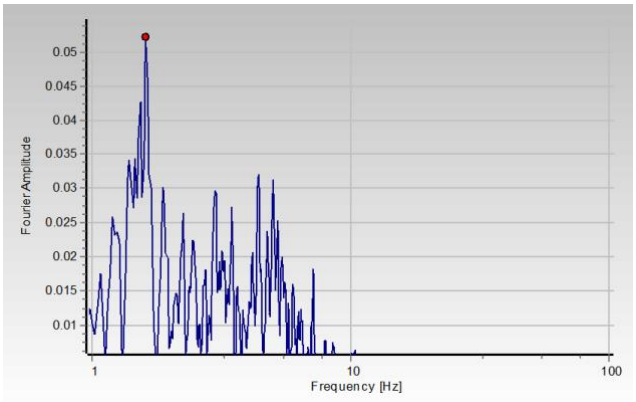

Fig. 13. Frequency content of the Coyote Lake earthquake

IV. CONCLUSION

The following conclusions can be drawn based on the results of the nonlinear time history analysis of the elevated water tank.

- The increased displacement demand of the empty tank, compared to the fully filled tank in the three specific cases of earthquake events (M1- Mammoth Lakes-04, M4- Coyote Lake, and S4-Mammoth Lakes-01), highlights the presence of a resonance effect.
- The displacement demand is not solely determined by a single factor, but rather it is influenced by a combination of factors, including peak ground

acceleration (PGA), duration, and earthquake magnitude.

- As expected, magnitude of the base shear tends to rise as the displacement demand of the structure increases.
- The observed lower natural frequency in the fully filled tank compared to the empty tank indicates that the added mass from the liquid content has a more significant effect on the tank's dynamic behavior compared to any potential increase in stiffness due to the liquid.
- While plastic hinges are formed during earthquakes with a PGA of up to 0.5g, it is essential to note that the structural integrity of the tank remains intact.
- The absence of plastic hinge formation under seismic conditions with a PGA around 0.1g indicates that, despite this type of tanks in Sri Lanka not being explicitly designed to withstand seismic forces, they exhibit a robust resistance to earthquakes of this magnitude. Consequently, it is evident that such tanks are unlikely to fail during the aforementioned seismic events.

In future research, the seismic analysis can be extended to evaluate the designed water tank's capacity under different earthquake records having higher PGA, various frequency contents, durations, and magnitudes. The effects of sloshing in the case of partially filled tanks can also be incorporated in the analysis. This would provide valuable insights into elevated water tanks' seismic resilience under more severe seismic conditions.

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2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

Performance Evaluation of Sasobit Modified Warm Mix Asphalt

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***Abstract*—In the road construction industry, many environmental and health issues have been increasing due to harmful gas and dust emissions. For that reason, the industry has provided a variety of technologies and additives to lower the production temperatures of asphalt mixtures. Warm-mix asphalt (WMA) is one of the newest and most popular techniques among others. Its road performance and workability can be equal to or better than hot mixture asphalt. Sasobit is one of the organic additives that can be used to decrease the binder viscosity and increase the workability of asphalt. It decreases the viscosity at the melting point of the wax and allows the asphalt mixtures to be compact at lower temperatures. Sasobit-modified warm mixture asphalt is normally made by adding specific sasobit percentage from the bitumen quantity when the aggregate is dry mixed. The mixing temperature of sasobit warm mixture asphalt may be reduced by 30–60°C when compared with hot mixture asphalt (HMA). As a result, it allows for a 30% reduction in energy consumption as well as a reduction in most hazardous gas and dust emissions.**

Keywords—Sasobit, warm mixture asphalt, workability, hot mixture asphalt, mixing temperature, compaction temperature

I. INTRODUCTION

Due to its advantages for the environment and capacity to enhance the engineering qualities of asphalt binders and mixtures, Warm Mix Asphalt (WMA) technology has grown in popularity in the pavement building industry [1].When compared to the control hot mix asphalt, warm mix asphalt is made, laid, and compacted at temperatures 10°C to 40°C degrees lower [2]. In any case, the performance of the mix has been questioned due to the lower mixing temperatures. In light of this, it is anticipated that the WMA mixes would be thoroughly evaluated and characterized to ensure adequate performance [3]. Because of its capacity to reduce the viscosity of the asphalt binder, Sasobit is referred as as an asphalt flow improver both during the asphalt mixing process and during laydown operations [4]. Sasobit WMA's performance in terms of resistance to rutting and cracking can be equal to or better than hot mixture asphalt [5]. Warm mix asphalt can easily be supplemented with Sasobit, which appears to be a practical technique for lowering mixing and compaction temperatures [6]. This research evaluate the optimum mix parameters for sasobit-modified WMA by adding range of 1%,2%,3%,4% and 5% percentages of sasobit additive from bitumen quantity while analysing the performance of the asphalt mixture to achieve the maximum benefit. Furthermore, evaluate the performance of sasobit modified WMA by adding optimum content of sasobit additive from bitumen quantity and check the engineering properties of the asphalt mixture with the mixing temperature range of 140°C and 145°C and compaction temperature range of 100, 105, 110, 115, and 120 °C to get maximum performance.

II. METHODOLOGY

The Marshall test was performed in the laboratory and the procedure was evaluated in following sections.

A. Collecting Materials

Sasobit additive and the bitumen was collected from the Bitumix (PVT) Ltd company, Homagama, Srilanka. The fresh aggregate was collected from the crusher plant near the Pitumpe, Padukka.

B. Asphalt Binder Selection

For asphalt binder, Bitumen (PG- 60/70) was selected with fresh aggregates to make the marshal mix designs.

C. Sample Preparation

In this research, 5 samples of aggregate-asphalt binder mix was used, each with the range of 4, 4.5, 5, 5.5 and 6% of asphalt binder content. Then, based on the performance of each sample blend, the optimum asphalt binder content was determined.

D. Optimum Binder Content Selection (OBC)

The optimum asphalt binder content was selected based on the graphs of combined results of Marshall Stability, Marshall Flow, density, Unit weight and Void in Mineral Aggregates (VMA) of each sample blend.

E. Mix Design Process

First, fresh aggregates for the samples were collected and sieved according to the ICTAD (Institute for Training and Construction Development) Wearing coarse type(II) aggregate gradation. Aggregate samples were heated on lab ovens at 150-170°C for 14 hours. Then the bituminous binder was heated at 170 °C for 2 hours. Then preheated specified bitumen content (4%-6%) mixed with aggregate samples at specified temperature of 160°C. After that the asphalt mix transferred into the pre heated mold and compacted at 150°C using the Automatic Marshall compactor to

prepare the Marshall blend sample. 75 blows were applied for the both side of the asphalt sample.

After 24 hours of curing at water bath, the compacted asphalt samples were heated at 60°C for 30-40min at water bath before testing. After that, Marshall Flow and stability tests were carried out for HMA samples using a Marshall testing machine accordance of the AASHTO T245-97(2001). Then optimum binder content was selected based on the graphs of combined results of Marshall Stability, Marshall Flow, density, Unit weight and Void in Mineral Aggregates (VMA).

Sasobit WMA samples were prepared by adding 1, 2, 3, 4, and 5% range of Sasobit from the weight of that optimum bitumen content. After that the mix design process was conducted with the mixing temperature of 140°C and 110°C compaction temperature. Then Marshall Test is conducted accordance of the AASHTO T245-97(2001).

After finding the optimum sasobit content, WMA samples were prepared using that optimum sasobit content. Then Following the previous mix design process for the different mixing temperature range of 135,140 and 145°C and compaction temperature range of 100, 105, 110, 115, and 120°C.

F. Data Analysis

Conducted the Marshall test for the asphalt samples of 4-6% bitumen content. Analysed the results and selected the optimum bitumen content.

Conducted the Marshall test for each sasobit WMA specimens. After that the test results of stability, flow density, unit weight for sasobit modified WMA samples were evaluated using graphs and charts. Then using the plotted graphs optimum mix parameters for sasobit WMA was determined and compared the results with HMA control sample.

Conducted the Marshall test for each WMA specimens which were prepared with different mixing and compaction temperatures. After that, the Marshall stability and flow test results for WMA samples were evaluated to check the temperature effects.

III. Results and Discussion

A. Optimum Binder Content

TABLE I. Marshall and Volumetric Properties of HMA Specimens

AC (%)	Va (%)	VMA (%)	VFA (%)	Unit Weight (Kg/m³)	Stability(KN)	Flow (0.25mm)
4	7.0	15.9	55.7	2.378	17.58	9
4.5	5.5	15.7	64.6	2.398	16.63	9.9
5	3.8	15.2	75.2	2.424	14.51	9.9
5.5	2.5	15.2	83.5	2.437	15.69	10.9
6	2.0	15.8	87.6	2.432	13.55	12.0

According to the requirement of ICTAD specification, the Marshall Stability should be greater than 8KN, Marshall Flow should be in 8 - 14 range, VMA value should be minimum 14 %, and Air voids should within the limit of 3-5%.

Analyzing the above results in accordance with ICTAD requirements, 4.8 % of bitumen content satisfied the required conditions.

B. Optimum mix parameters for Sasobit modified WMA

TABLE II. Marshall and Volumetric Properties of The Sasobit Modified WMA

SASOBIT Content	Air Voids (Va) (%)	VMA (%)	Stability (KN)	Flow (0.25mm)	Unit Weight (Kg/m³)	Density (Kg/m³)
HMA Control Sample	4.915	15.189	15.085	9.600	23.926	2.439
SASOBIT 1%	3.353	14.262	11.272	15.600	24.224	2.466
SASOBIT 2%	3.258	14.177	14.976	13.200	24.212	2.468
SASOBIT 3%	3.237	14.158	15.500	10.600	24.217	2.469
SASOBIT 4%	4.115	14.938	14.960	12.200	23.997	2.446
SASOBIT 5%	4.915	15.648	14.060	13.400	23.797	2.426

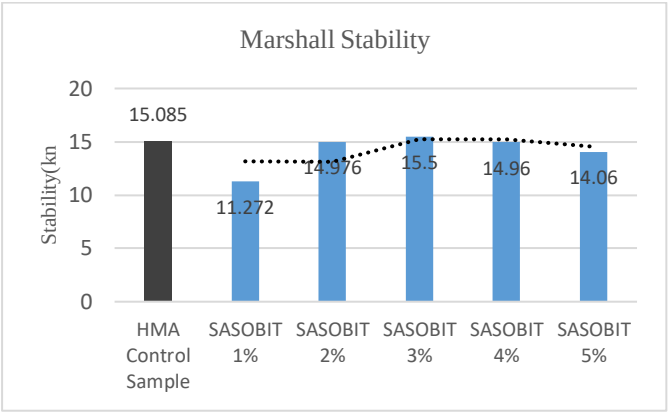

Fig. 1. Marshall Stability results of the Sasobit modified WMA

Fig. 1 shows that as the sasobit percentage increases, the marshall stability values also increased within the range of 1-3% of sasobit samples. After the 3 to 5% of sasobit, Fig 1, shows that the marshall stability values were decreased. Moreover, all the values listed in TABLE II met the specified requirements of the ICTAD specification. Highest marshall stability values showed 2% and 3% of sasobit. Furthermore, when compared with the HMA control sample, the 3% of sasobit shows the maximum stability value. A higher marshall stability value indicates that an asphalt mixture can withstand the higher loads before deforming and failing. Also, it measure the strength and ability to resist deformation under the applied load of the asphalt mixture. Moreover, it is proven that by adding sasobit the strength of the WMA marshall mixture can be increased when compared with HMA. Therefore the 3% of

sasobit shows that the optimim sasobit content when analyzing the marsahll stability values.

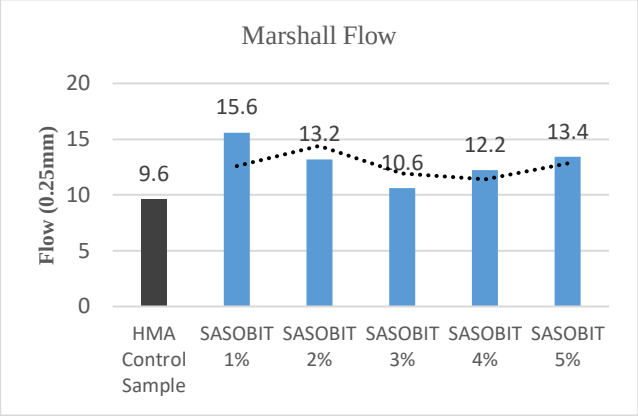

Fig. 2. Marshall Flow results of the Sasobit modified WMA

The marshall flow value is measured by the deformation of the asphalt mixture as it flows laterally under the specified load and temperature conditions. The higher marshall flow values indicated that the asphalt mixture is relatively softer and it can lead to rutting under high traffic loads. Therefore lower flow values indicated that the asphalt mixture is stiffer and resists deformation under high traffic loads. Therefore lower flow values were more preferable. According to Fig. 2, when sasobit content increased 1-3% the marshall flow values were significantly decreased and at 4-5% sasobit content, the Marshall flow values increased. Also, it clearly shows that the 3% of sasobit is the lowest flow value. Furthermore, when compared with the HMA control sample the flow value of sasobit 3% is higher than the HMA mixture. It suggests that by adding sasobit, the asphalt mixture becomes relatively soft, more workable during construction and advantageous in achieving proper compaction. Therfore, it can be suggested that the 3% of sasobit is the most preferred content when analyzing the results of marshall flow.

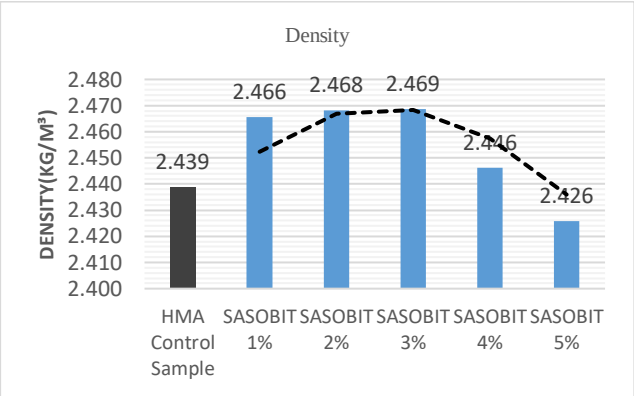

Fig. 3. Density results of the Sasobit modified WMA specimens

According to Fig. 3, when the content of sasobit increases up to 1 to 3%, the density of the bitumen mixture increases, and the density of the mixture decreases from 4 to 5% sasobit. Higher density values indicated that the asphalt mixture has been well compacted and can lead to improve the durability and resistance to rutting and cracking under the highly traffic roads. Fig.3 shows that the highest density value was the 3% of sasobit and when it compared with the HMA control sample, the sasobit WMA mixture is more densly compacted than HMA mixture. Therefore, it can be suggested that the 3% of sasobit is most suitable content when analysing the above results.

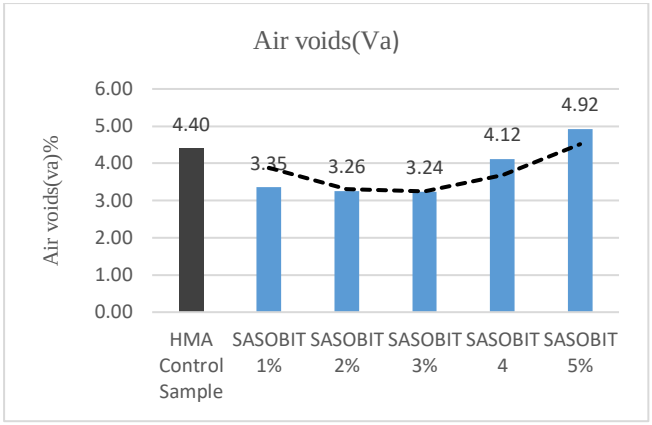

Fig. 4. Air void results of the Sasobit modified WMA

According to the Fig.4, all the values were within the specified requirements of the ICTAD specification. The highest air void value is the 5% of sasobit and the lowest air void value indicated the 3% of sasobit content. Lower air void values suggested that the asphalt mixture was densly compacted and it's normally caused to improve the durability. When compared with the HMA sample, air voids of 3% sasobit lower than HMA.

C. Effects of the Mixing and Compaction Temperatures on the Performance of Sasobit Modified Warm Mix Asphalt

TABLE III. MARSHALL AND VOLUMETRIC PROPERTIES OF THE SASOBIT WMA WITH MIXING AND COMPACTION TEMPERATURE RANGES

Sample No.	Va (%)	VMA (%)	Stability (KN)	Flow (0.25mm)	VFA (%)
HMA Control Sample	2.49	13.75	15.09	13.20	79.83
M 135, C 100	4.12	14.94	12.06	12.80	72.43
M 135, C 105	2.61	13.60	15.09	11.60	80.82
M 135, C 110	4.27	15.07	12.66	11.60	71.68
M 135, C 115	2.57	13.57	12.66	13.20	81.04
M 135, C 120	2.49	13.50	14.39	9.60	81.53
M 140, C 100	2.77	13.75	12.66	12.40	79.83
M 140, C 105	4.00	14.84	10.90	11.60	73.03
M 140, C 110	3.11	14.05	13.24	11.20	77.83
M 140, C 115	3.44	14.34	13.24	12.40	76.02
M 140, C 120	3.54	14.43	14.96	12.40	75.44
M 145, C 100	4.11	14.94	12.06	11.20	72.46
M 145, C 105	3.95	14.79	13.24	10.80	73.31
M 145, C 110	3.63	14.51	13.84	12.80	74.97
M 145, C 115	3.23	14.15	14.30	9.20	77.19
M 145, C 120	3.18	14.11	15.56	9.20	77.44

M-Mixing Temperature, C- Compaction Temperature

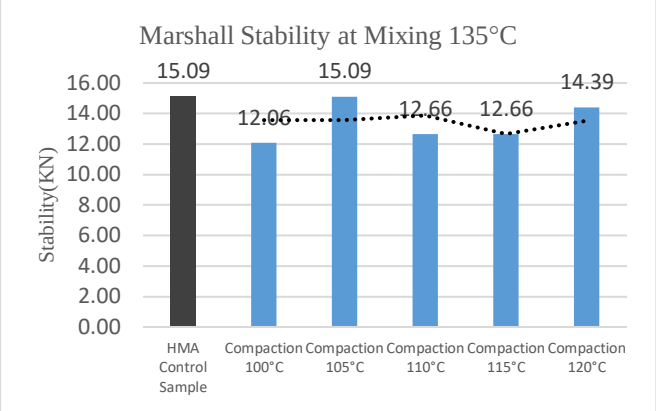

Fig. 5. Marshall Stability results of the Sasobit modified WMA with 135 °C Mixing temperature

The Fig. 5 illustrates the stability values for compacted in 100, 105, 110, 115, 120 °C temperatures and mixed in 135 °C temperature of sasobit modified warm mix asphalt samples. According to the above graph highest value of stability shows in 105 °C compacted sasobit modified WMA when comparing with hot mix asphalt (HMA) control sample.

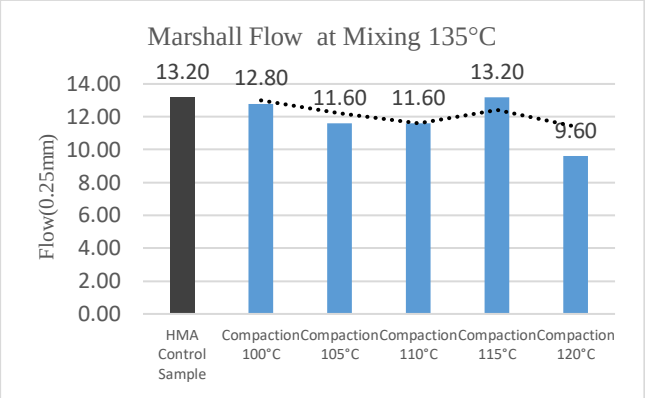

Fig. 6. Marshall Flow results of the Sasobit modified WMA with 135°C Mixing temperature

The graph shows in Fig. 6 compares the flow values of compacted samples in the 100,105,110,115,120 °C temperatures and mixed in 135 °C temperature of sasobit modified warm mix asphalt. In sharp contrast to this ,lowest flow value were seen in 105 and 110 °C compacted sasobit modified warm mix asphalt samples when comparing with HMA control sample.

The graph in Fig. 7 shows that the stability values for compacted in 100,105,110,115,120 °C temperatures and mixed in 140 °C temperature of sasobit modified warm mix asphalt samples. In conclusion highest value of stability shows in 120 °C compacted sasobit modified warm mix asphalt when comparing with hot mix asphalt (HMA) control sample.

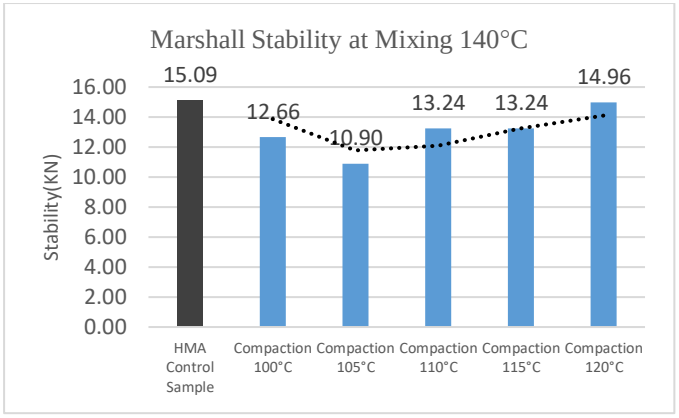

Fig. 7. Marshall Stability results of the Sasobit modified WMA with 140°C Mixing temperature

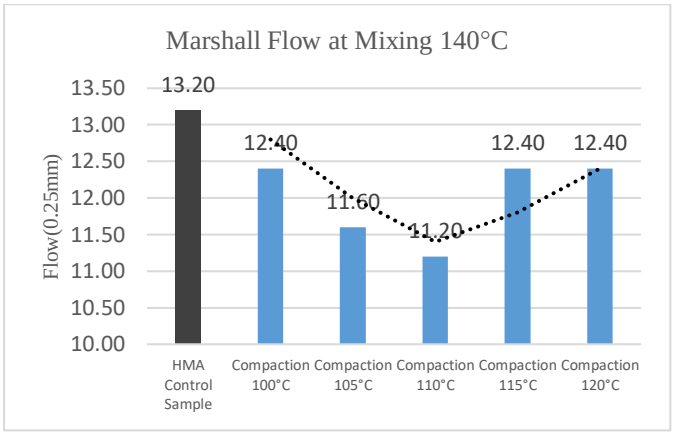

Fig. 8. Marshall Flow results of the Sasobit modified WMA with 140°C Mixing temperature

The Fig. 8 illustrates the flow values of compacted samples in the 100,105,110,115,120 °C temperatures and mixed in 140 °C temperature of sasobit modified warm mix asphalt. However, the flow was lowest at all time for the 110 °C compacted sasobit modified warm mix asphalt samples when comparing with HMA control sample.

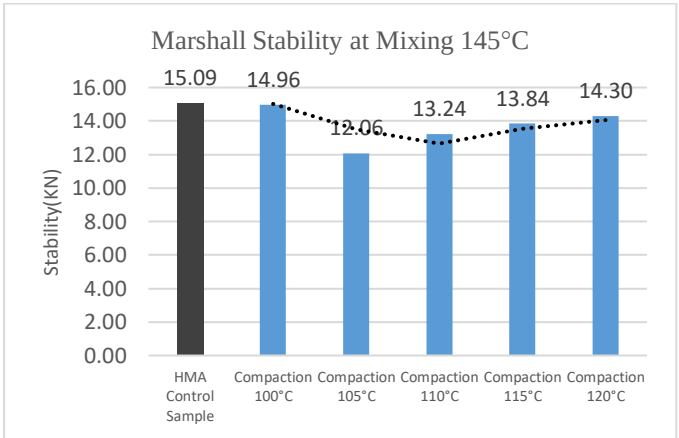

Fig. 9. Marshall Stability results of the Sasobit modified WMA with 145°C Mixing temperature

The graph shows in Fig.9 is describing the results of stability values for compacted in 100,105,110,115,120 °C temperatures and mixed in 145 °C temperature of sasobit modified WMA samples. The graphs shows highest value of stability in 120 °C compacted sasobit modified WMA when comparing with HMA control sample.

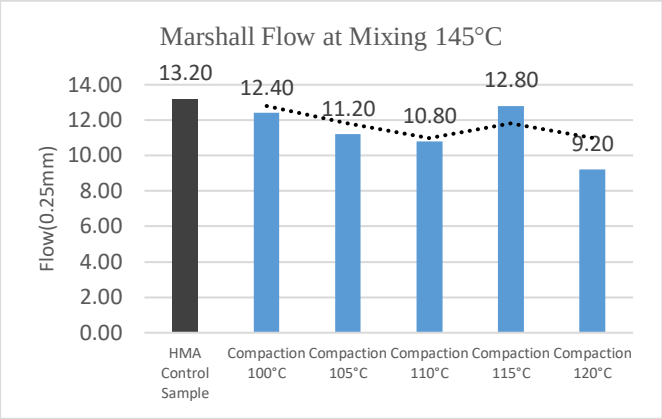

Fig. 10. Marshall Flow results of the Sasobit modified WMA with 145°C Mixing temperature

The graph in Fig. 10 shows the marshall flow changes of compacted samples in the 100,105,110,115,120 °C temperatures and mixed in 135 °C temperature of sasobit modified WMA. It is clear from the graph that, lowest flow value were seen in 110 and 120 °C compacted sasobit modified WMA samples when comparing with HMA control Sample.

IV. Conclusion

From this Study, the following conclusions can be made:

1. The highest Marshall Stability value shows the 3% sasobit modified WMA specimen and it is higher than the HMA control mixture.
2. All the samples apart from 1% sasobit modified WMA are within the range of Marshall Flow which is required in ICTAD specifications. 3% sasobit WMA is lowest Flow value among other samples and when compared with the HMA, it's higher than the HMA control sample.
3. When consider about the Density, the 3% sasobit WMA shows the highest density and it is more densly compacted than the HMA specimen.
4. All the sasobit modified WMA samples are within the range of Air Voids which is required in ICTAD specifications
5. From the mixing temperature ranges of 130, 135 and 140°C with the compaction of 100,105,110,115,120 °C, the highest Marshall Stability value shows the 145°C mixing and 120°C compaction sasobit-modified WMA specimen and its performance is better than the HMA control mixture.
6. When considering about the Marshall flow, from the mixing temperature ranges of 130, 135 and 140°C with the compaction of 100,105,110,115,120 °C, the lowest flow value shows the 145°C mixing and 120°C compaction sasobit-modified WMA specimen and it is also stiffer than the HMA control mixture and resists rutting under high traffic loads.

According to the results shown in Table II and III, all the Marshall and volumetric properties are within the requirements of ICTAD specification. The results and graphs shows that the 3% sasobit WMA sample has indicated the highest Stability and density values and lowest flow value among other WMA samples. Moreover, results shows that its performance and workability were better than the HMA specimen. Furthermore, analyzing all the details of Marshall and volumetric properties can conclude that the 3% sasobit modified WMA is most preferable and optimum sasobit content for the Sri Lankan contest as it follows all the requirements mentioned by ICTAD specification. Moreover, analyzing the results of mixing and compaction temperature ranges of WMA, at 145°C mixing and 120°C compaction, the Sasobit-modified WMA shows the best performance among all other specimens.

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2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

A Review on The Utilization of Geosynthetics and Natural Fibers in Enhancing the Pavement Subgrade Strength

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***Abstract*—The practice of reinforcing subgrade soil to improve its strength, a technique with roots dating back centuries, remains a crucial engineering endeavor, particularly in regions plagued by weak subgrades and challenging soils like expansive silts and clays with high swelling-shrinkage characteristics and low-bearing capacity. The conventional method of subgrade modification through excavation and replacement, marked by its exorbitant costs and time-consuming nature, has given way to alternative solutions, prominently natural and synthetic reinforcement methods. Geosynthetics including polypropylene fibers (PP), polyethylene fibers (PE), polyester fibers (PET), glass fibers, nylon fibers, steel fibers, and polyvinyl alcohol fibers (PVA), are widely employed for this purpose. Additionally, eco-friendly and cost-effective natural fibers like coir, sisal, palm, jute, hemp, bamboo, and kenaf fibers are gaining attraction. These fibers, their lengths, compositions (typically within the range of 0.2% to 1.5% of soil weight), and arrangements within soil samples have been subjected to extensive experimentation. Through laboratory analysis and testing, including sieve analysis, sedimentation analysis, Atterberg limits, and Standard Penetration Cone (SPC) tests, researchers have consistently demonstrated that reinforced soils exhibit improvement in shear strength, axial strain due to failure, load-bearing capacity, and California Bearing Ratio (CBR) strength. These findings underscore the potential for efficiently stabilizing problematic soils for road pavement construction using both natural and synthetic fibers, ultimately enhancing subgrade performance. This comprehensive review highlights the value of stabilizing problematic soils for constructing road pavements using natural and synthetic fibers.**

Keywords—Subgrade modification, geosynthetic, natural fiber, reinforcement, pavements

I. INTRODUCTION

A. The Significance of Soil Reinforcement

The construction and maintenance of pavements are considered a vital infrastructure component. It is stated that the soil can be classified into four types: gravel, sand, silt and clay. Certain soils have low shear and tensile strengths, and their other properties also rely on the surrounding environmental factors [1]. Another efficient and dependable method in improving the technical attributes of soil is the incorporation of reinforcing inclusions [2].

Stabilization is a technique of improving the engineering attributes of soil by utilizing different compounds to guarantee that it is appropriate for construction [3]. Numerous techniques have been developed over time, particularly for ground improvement and soil stability. These techniques can be roughly categorized into three different kinds: mechanical, chemical, and physical [4]

B. Methods of Soil Reinforcement

Soil reinforcement can be done in three ways; physical, chemical, and mechanical. Reinforcement can further be divided into two main groups: preferably inextensible inclusions which are metal strips and bars and ideally extensible inclusions known to be natural and synthetic fibers[4]. When soil reinforcement first began, the weak soil layer was removed and replaced with a more acceptable soil layer. However, this method is tedious and costly. Therefore, engineers' resort to the use of geosynthetics such as geotextiles, geogrids, geomembranes, and geo-composites [5].

II. REINFORCEMENT OF SOIL BY FIBERS

A. Alternatives to Traditional Methods of Reinforcement

Natural fibers are readily available, often nonabrasive, and absorb nitrogen and phosphorus from the soil as well as carbon dioxide from the air at a very high rate [6]. Alternatives such as using natural and synthetic fibers are becoming popular nowadays. Research conducted has shown desirable effects on the engineering properties of soil once it has been incorporated with fiber [7] A variety of natural fibers, also known as "eco-composites", including bamboo, sisal, jute, flax, barely straw, and coconut coir, have been investigated as stabilizers to improve the qualities of soil [8]. Whereas types of synthetic (man-made) fibers [9] include polypropylene fibers (PP)[10][4], polyethylene fibers (PE), glass fibers[11], nylon fibers, steel fibers, polyester fibers (PET) and polyvinyl alcohol fibers (PVA). The distribution of fiber orientation greatly affects how the fibers causes changes to the strength and failure of fiber-reinforced soil [7].

B. Natural Fibers–Various Treatment Methods

1) Physical Treatments: Studies on the morphology of coir fibers reveal the lignin sheath that surrounds the cellulose fibers. Usually, removing this lignin layer from the surface yields a better and more stable matrix. Understanding the characteristics of the cell wall segments and how they relate to fiber characteristics is crucial to realizing how fibers of lignocellulosic can be used in high-performance industrial applications [12]. Natural fibers carry amorphous regions, other polar groups as well as hydroxyl compounds that increase its ability to absorb moisture while leading to a descending manner in the mechanical properties of the fiber, which ultimately leads to biodegradation [13]. Physical techniques improve fiber-matrix cohesiveness by altering surface qualities rather than the structural makeup of the fibers. Corona, plasma, ultraviolet (UV), fiber pounding, and heat therapy are examples of physical treatment methods. These methods are only used to alter the characteristics of natural fibers surfaces [14]. Many natural fibers' surfaces have been effectively modified via plasma treatment. Mechanical characteristics of natural fibers were found to greatly improve after plasma treatment. Similar to plasma treatment, surface etching caused by it may increase surface roughness and produce a better interface[12]. The UV treatment approach improves the polarization of the fiber surface, improving fiber moisture adsorbtion and boosting overall strength [15]. An increase in the resilience of natural fibers by 10% can be achieved by using the fiber-beating method, increasing the surface area, defibrillating the fibers, and mechanical interlocking. In heat treatment, heat is applied to fibers to a degree slightly below the point at which they break down. This situation affects the fibers' mechanical, chemical, and degree of polymerization as well as their chemistry, strength, and water content [12], [13].

2) Chemical Treatments: The adhesion between the matrix and natural fibers is strengthened by chemical processes[16]. Usually natural fibers can be treated chemically by means of alkali (mercerization), silane treatment, peroxide treatment, etc. It has been shown that with an alkali treatment, where the fiber is treated with sodium hydroxide (NaOH), the mechanical properties can be improved significantly by modifying its crystalline structure and removing hemicellulose and lignin from its structure [13] In order to enhance the chemical interactions between natural fibers and the polymeric matrix, silanes are a favourable and adaptable class of coupling agents [12], [16].

III. Existing Literature on Natural and Synthetic Fibers on Soil Reinforcement

A. Case Studies on Subgrade Improvement by Natural Fibers

With the abundance of natural fibers in several countries, engineers have paid a fair amount of interest in the application of natural fibers on soil reinforcement. The vitality of natural fibers in the contemporary construction industry is defined by the term "eco-composite.". Many studies have been conducted to evaluate the improvement of subgrade strength by the combination of fibers with the problematic soil in question.

1) Coconut (coir) Fibers: The coconut tree, *Cocos nucifera* (L.) (Arecaceae), is made up of the drupe, or edible fruit, which has a fibrous husk covering it. (mesocarp). This mesocarp is available in two types; namely brown fiber and white fiber, where the brown fiber is the more mature and dried-up fiber from the husk that is used to produce several household and industrial placement items such as geotextiles. In a study conducted by [17] uses brown–washed coir in percentages of 0% to 1% with an increment of 0.25% of 20mm length, added in a discrete arrangement. A California Bearing Ratio (CBR) test was conducted on the parent soil sample and the reinforced sample, and it was concluded that the strength of the soil improve with the increasing number of reinforcement layers (specifically at a depth of 1/3 of soil). In another study conducted on problematic soil mixing four types of fiber; including coir fiber, were also added in percentages of (0.5% to 1%) with a gradiation of 0.25% of the weight of the soil. An extreme learning machine (ELM) approach was used in this study and it showed that the use of coir fiber increased the soil-fiber density, further increasing the strength of the subgrade [8] [18] has incorporated coir fiber geotextiles in the process of improving the subgrade soil and has found out that the bearing capacity improved with the reinforcement by 1.83 times, the soaked California Bearing Ratio (CBR) value was improved and that the durability of a coir geotextile was about four to six years depending on the chemical and physical properties of the soil. [19] conducted research on the use of coir fiber as well as thermoplastic waste in subgrade modification where they found out that the tensile strength and flexural strength of the soil improved with the fraction of fiber used between 20%-30% of its total weight of soil. Another research conducted by [20]showed that the use of coir fiber (CF) in clay soil improved the subgrade by increasing its CBR value with the inclusion of CF. Another study conducted by [21] used fiber content of 0.2% to 1% with an increment of 0.2% by weight of soil. The results showed that the CBR strength of the soil sample increased by 4.6 times. A study conducted with the use of coir fiber showed that the CBR strength of soil yields higher strength with the addition of 0.3% fiber into the soil mixture [22].

2) Sisal Fibers: Agave sisalana, a succulent plant of the *Agave genus*, produces the leaves that are used to make sisal, a natural fiber. In arid or semi-arid locations, like sections of Africa, South America, and Asia, sisal plants are largely grown. A study used a random inclusion of 0.25% to 1.0% of sisal fiber by weight of subgrade soil. The fiber was used at a desired length of 30mm. The prepared subgrade samples were soaked to cause capillary rise. According to the test results, the capillarity impact caused the tensile and compressive strengths of 10 kPa and 20 kPa pre-compressed specimen to drop from an average of 1.48 MPa to 0.98 MPa when compared to non-capillary specimen. Without capillary effects, a strength gain of 12.21% and 63% would be comparable. Compared to un-pre compressed specimens evaluated under tension, 11 were recorded for pre-compressed specimens at 10 kPa and 20 kPa.

The test results were obtained by conducting a splitting tensile strength (STS) test [23]. Another study done by [24] on black cotton soil by the inclusion of sisal fiber in 0.25% to 1.50% with a gradation of 0.25% of the weight of soil. The soil was further mixed with rice husk ash in equal amounts and the test was concluded showing that a percentage of 0.75% of fiber provides a maximum value of 7.22 (being 4.24 times greater than the control sample) in terms of CBR strength. For fiber lengths of 10, 15, and 20 mm, varied percentages of sisal fibers were utilized to evaluate various compaction metrics, including California bearing ratio (CBR), and unconfined compression strength tests (UCS). According to the literature used, the maximum density (MDD) of soil mixed with fiber somewhat dropped as fiber content and length increased, although the ideal moisture content (OMC) slightly increased. With increasing fiber length and content, the California bearing ratio (CBR) and unconfined compressive strength (UCS) both rose remarkably; this rise was evident at 15 mm fiber length and fiber content of 1.5% [25].

3) Palm Fibers: A study was conducted on the effects of adding palm fiber with lengths between 30 and 35 mm and percentages between 0.1% and 1.0% by weight of soil on the strength of subgrade soil. A number of laboratory experiments, such as compaction, an unconfined compression test, and a 4-day soak California bearing ratio test, were performed on it. According to the findings, the maximum density reduced as the fiber content improved while the ideal moisture content increased. The maximum soaking CBR value for palm fiber inclusion was 14%, and the unconfined compression value was 352 kPa. These peak values were found at 0.2% fiber, which is the ideal fiber content [26].

4) Jute Fibers: A natural plant-based fiber known as jute,

Corchorus Olitorius, and *Corchorus capsularis*, is harvested from the plant's stem. In countries with tropical climates, such as India, Bangladesh, and other areas of Southeast Asia, jute is largely farmed. Two types of clayey soil were used in the study. The soil was mixed with 0.25 to 1.25 percent jute fiber, with increments of 0.25 percent and length variations of 0.5 to 1.5 centimeters. The samples underwent optimum moisture content tests, unconfined compression (UCC) tests – to obtain the shear strength parameters of cohesive soils, unconfined compressive tests (UCS) – to determine the soil failure point in compression at a given load per unit area, and California Bearing Ratio (CBR) tests to evaluate their strength improvement in relation to its control sample. Results showed that the 1cm fiber with a percentage of 0.75% fiber content showed an increase in both UCS and CBR values, providing evidence that jute fiber is a good reinforcement material for problematic soils [27]. A research conducted by [28] where jute fiber of 25mm length was mixed with the soft soil by percentages varying from 0.25% to 1.0% by weight of soil. then its fundamental characteristics were identified, including compaction characteristics, unconfined compressive strength, and California bearing ratio in both soaked and unsoaked circumstances. The results showed that with the addition of the jute fiber, the CBR strength of the sample was increased from 2.8% to 6.5% under soaked conditions. A study conducted on clayey soil with a variation of jute fiber percentages from 0.3% to 0.9% was also done. The addition of jute fiber with a 0.6% content and a length of 6 mm to soft soil specimens arranged at the maximum density and ideal moisture content produced the most effective fiber-reinforcing effects [29].

5) Hemp Fibers: Hemp fiber is a natural fiber derived from the stalks of the hemp plant (*Cannabis sativa*) [30] To evaluate the strength parameters of clay with hemp fiber reinforcement, a study was conducted with a specimen of control clay sample mixed with fiber percentages which vary from 0.5% to 1.5% with a gradation of 0.25%. The length of hemp fibers was kept constant at 4cm. The samples then underwent a series of tests to evaluate their undrained shear strength characteristics and were successful in providing that the strength of fiber-reinforced clay indeed improved from 0.5% to 1.25% and then decreased from then onwards. The optimum fiber content was determined to be 1.25% [31]. Further research on the effectiveness was done by [32] where they included a mixture of hemp fiber and coir fiber in percentages of 0.1% to 0.4% by mass of black cotton soil treated with alkali-activated binder. The length of the fiber was kept at 25mm. the results concluded that it increased the resilience of soil fibers to freeze-thaw cycles. The strength-bearing ratio was considerably enhanced in terms of CBR performance by the formation of active cementitious bonding and interfacial friction along the exterior of fiber and clay particles. A further investigation was done on a soft soil subgrade that was combined with an alkali-activated binder and included 0.2% to 0.8% of fiber by weight of the soil. This was an extension of the research done by [32]and[33].

6) Bamboo Fibers: Bamboo fiber is yet another natural fiber that is currently being used in the modification of subgrade strength. Many researchers did study on a soil sample by reinforcing it with bamboo fiber at varied percentages from 0.2% to 1.4% with an increase of 0.2%, as the strength characteristics of the subgrade mostly depend on the CBR value of the reinforced soil sample. The length of the fibers was selected to be 10mm and 20mm. The CBR value of common soil is raised and ductility behavior is improved by the combination of fiber with soil. According to the test results, soil's CBR value when and wet rises as bamboo fibers are longer and bigger in diameter. Additionally, it was discovered that adding more bamboo fiber raises the CBR value of reinforced soil; this increase becomes significant at 1.2% of the total amount of fiber. The thickness of the pavement will decrease due to this significant increase in CBR value [34]. To investigate further the effectiveness of using bamboo fiber, [35] added a ratio of 1% to 5% of fiber percentages to a problematic soil and found out that there was a tendency of all specimens compressive stresses to rise as the amount of bamboo fiber in them rose. Bamboo fiber content of 0%, 1%, 3%, and 5% had maximum compressive stresses of 115, 108, 130, and 152 kN/m2, respectively.

7) Kenaf Fiber: Research conducted by [6] investigates the effectiveness of the engineering behavior of clayey soil with the inclusion of kenaf fiber. The kenaf fiber was used in varying percentages of 0.25%, 0.50%, and 0.75% of the weight of the soil sample. An advantage of kenaf fibers in terms of volume change was found to be that they decreased the specimen's initial constriction (up to 34%) and the subsequent dilation (up to 40%). The relationship between fiber mixed clay contents and the variation of the brittleness index showed that fibers had a stronger impact on improving soil mixture ductility than clay content did. Additionally, when the proportion of fiber in the mixture rises, the shear strength parameters, which are internal friction angle and cohesion, dramatically improved by 15% and 13%, respectively.

B. *Case Studies on Subgrade Improvement by Synthetic Fibers*

An alternative to natural fibers, in geotechnical engineering, short synthetic fiber soil composites have garnered increased attention lately. In geotechnical projects, they are still a relatively new method. Several different kinds of synthetic fibers, including those made of polypropylene, polyester, polyethylene, nylon, steel, and glass, are currently in use.

1) Polypropylene Fibers: The thermoplastic polymer polypropylene is used to create the synthetic fiber known as polypropylene fiber (PP fiber). It has a nice mix of stiffness and impact strength and is lightweight, strong, and water-resistant. Additionally, PP fiber is unaffected by insects or mildew and is resistant to most of acids and alkalis. In a research conducted by [36], the mechanical properties and strength of silty sand reinforced with short resinous Polypropylene (PP) fibers arranged at random were examined in laboratory uniaxial compression experiments. The fibers were of percentages; 0.25% to 0.75% of the weight of soil and in lengths of 1.5cm, 2cm, and 3cm. It was found that the fibers of length 1.5cm showed a drastic improvement in the strength of the reinforced soil. Another research conducted on single fiber pull-out tests assessed the parameters influencing the interfacial strength properties of soil reinforced with polypropylene fiber (PP-fiber) [3]. Four different fiber content percentages (0.25%, 0.50%, 0.75%, and 1.0%) and three different fiber lengths (6 mm, 12 mm, and 20 mm) of reinforced stabilized soil specimens were established in order to conduct additional studies on the efficacy of this fiber. After seven and twenty-eight days of curing, tests for unconfined compressive and split tensile strength were conducted. The maximum values for strength were found to contain between 0.5% and 0.75% of the 12 mm-long fibers. [37] A study conducted by [4] showed that a fiber ratio of 0.4% to 0.8% of weight of soil proved maximum strength within a varying ratio of 0% to 1%.

2) Polyester Fibers: A synthetic fiber created from petroleum products is called polyester fiber. One of the most widely used fibers worldwide, it can be discovered in many different products, including clothing, household goods, and industrial products. A study focused on the impact of the subgrade soil's technical attributeswhen recycled polyethylene terephthalate (PET) fibers were incorporated with fly ash. Shear strength, shear modulus, California Bearing Ratio (CBR), indirect tensile strength, and Atterberg limits using clayey soil were the technical attributesthat were specifically investigated. The usage of variables ranging from 0% to 1.6% by the weight of the soil with a gradation of 0.4% for PET fibers resulted in an improvement in shear strength, a decrease in plasticity index, and a CBR value. The ideal proportion was found to be 1.2% recycled PET fiber and 15% fly ash by soil weight, which enhanced the strength metrics of the subgrade soil [38]. Another research conducted by [39] to determine the impact of polyester fiber content on the strength behavior of the tested soil, Unconfined compressive strength tests (UC) and consolidated undrained (CU) triaxial compression tests were conducted on clayey soil specimens that were compacted, untreated, and treated with lime and cement. The specimens were reinforced with varying percentages of polyester fiber (i.e., 0%, 0.05%, 0.1%, and 0.2% by weight). According to test results, adding lime or cement significantly increased strength and strength metrics. The application of fiber contents from 0% to 0.2% was found to enhance strength by a factor in the range of 2.3 to 4.6.

3) Polyethylene Fibers: Polyethylene, a thermoplastic polymer, is used to create synthetic polyethylene fibers, which are high-performance materials. A study was conducted to find the effectiveness of using polyethylene terephthalate (PET) fibers in subgrade improvement with proportions ranging from 0% to 1.6% of fiber with the weight of soil. The experimental studies' findings show that using fiber increased the shear strength, CBR value, and plasticity index. The most suitable amount was determined to be 1.2% recycled PET fiber and 15% fly ash by soil weight, increasing the strength parameters of the subgrade soil [38].

4) Glass Fibers: Glass fiber, sometimes referred to as fiberglass, is a strong, lightweight material manufactured from incredibly tiny glass strands. These strands are frequently woven into fabrics or utilized in a variety of composites as a reinforcing material. Researchers used random and discrete fiberglass reinforcement to study the effects of expanding subgrade. The fiber content used in this study was within the percentage range of 0.25% to 1.0% by weight of soil. On unreinforced and reinforced expansive soil specimens, many tests were carried out, including those for free swell, unconfined compressive strength (UCS), indirect tensile strength (ITS), and California bearing ratio (CBR). According to the test results, adding glass fibers to subgrade soil dramatically raises the UCS, ITS, and CBR values while lowering the free swell values [11]. In another study conducted by [40], fiberglass with percentages from 1% to 6% was used on the soil selected to provide a uniform blend. Then the specimen was tested under several tests for its strength characteristics. The findings demonstrated a 2.4 improvement in tensile strength at soil reinforced with 3% to 5% fiber glass.

5) Steel Fibers: Steel fibers are short, small-diameter metallic fibers typically composed of a variety of steels, such as stainless and carbon steel. A study was done to assess the

efficiency of Fly Ash and/or Cement-modified, Steel Fiber-reinforced Marginal Soil (Clayey Sand). These qualities for the goal of subgrade construction, strengthened with steel fiber, Marginal Soil Modified with Cement and/or Fly Ash was investigated in order to increase CBR value. In the current study, steel fibers with a diameter of 0.5 mm and lengths of 1 to 2 cm were employed. A 4% by-volume addition of steel fibers was made to the marginal soil which increased it's strength parameters [41].

IV. Future Works

It is important to highlight that the true behavior of fiber-reinforced soils is still poorly understood due to lack of research on the effects of scale effects and soil and fiber engineering features on the stress-strain-strength characteristics of fiber-reinforced soils. As a result, additional research, particularly large-scale tests by means of using physical models representing natural conditions, are required to comprehend the behavior of fiber-reinforced soils. More information on its effectiveness of using synthetic fibers is needed in terms of durability.

V. Conclusion

This review paper examines the idea of employing short fiber soil composites, or discrete randomly distributed fibers in soil. In this manner, the currently utilized natural and synthetic soil reinforcement fibers (coir, sisal, palm, jute, bamboo) as well as glass and steel were examined. Fibers are added at a dose rate of roughly 0.2–4% by weight to silt, clay, sand, or soil that has been stabilized with lime and cement in a simple process. All of the aforementioned publications have typically demonstrated that fiber reinforcing improves the strength and stiffness of composite soil. We may draw the conclusion that the claimed improvement in strength and stiffness was a result of the soil, fiber, and testing circumstances. Technical benefits of using fibers in soil reinforcement include reducing the occurrence of tensile cracks, raising hydraulic conductivity and liquefaction strength, lowering thermal conductivity and weight of building materials, lowering the propensity of expansive soils to swell, and lowering soil brittleness. It is emphasized that the use of natural fibers is more effective in strength gained than the use of synthetic fibers due to their economical availability and renewability.

TABLE 1 Summary of Existing Literature

Author/Date	Aim of Study	Variables	Main findings
D. Kaushik and Sitesh Kumar Singh 2021	Effectiveness on the geotechnical properties of soil.	Brown washed coir 0% - 1% with an increment of 0.25% of 20mm in discrete arrangement	Increase of strength with the increasing number of layers
N. Karthi, K. Kumaresan, S. Sathish, S. Gokulkumar, L. Prabhu, and N. Vigneshkumar 2019	Improving the strength of the subgrade.	four types of fiber; including coir fiber, were also added with a step of 0.25% of the soil's weight in percentages ranging from 0.5% to 1% ELM approach	Bearing capacity improved with the reinforcement by 1.83 times. CBR value was improved. Durability of a coir geo textile was about four to six years.
D. P. Ferreira, J. Cruz, and R. Fangueiro 2018	Subgrade modification.	Coir fiber and thermoplastic between 20%-30% of its total weight of soil.	Textile and flexural strengths of the soil improved with the fraction of fiber used in between 20% - 30% of its total weight of soil.
R. Mello, Maria Virginia Gelfuso, and D. Thomazini 2015	Subgrade soil improvement in terms of CBR strength.	Coir fiber in clay soil	Improved the subgrade by increasing its CBR with the addition of coir fiber.
Mehdi Valipour, Piltan Tabatabaie Shourijeh, and Alireza Mohammadinia 2021	Subgrade soil improvement in terms of CBR strength.	0.2% to 1% fiber content, increased by 0.2% based on the weight of the soil.	CBR strength of the soil sample increased by 4.6 times.
S. O. Amiandamhen, M. Meincken, and L. Tyhoda 2020	Subgrade soil improvement in terms of CBR strength.	Coir fiber of 0.3% into the soil mixture in discrete arrangement.	CBR strength of soils yields higher strength with the addition of 0.3% fiber into the soil mixture.
Aliakbar Gholampour and Togay Ozbakkaloglu 2020	Effects on the tensile and compressive strengths of soil by STS test.	Random inclusion of 0.25% to 1.0% of sisal fiber of 30mm by the weight of subgrade soil.	Capillarity impact caused the tensile and compressive strengths of 10 kPa and 20 kPa pre-compressed specimens to drop from an average of 1.48 MPa to 0.98 MPa.
Mazahir M.M. Taha, Cheng Pei Feng, and	Impact of sisal fiber addition on the CBR	inclusion of sisal fiber in 0.25% to	0.75% of fiber provides a maximum

Sara H.S. Ahmed 2020	strength of black cotton soil.	1.50% with an increment of 0.25% of the weight of soil.	value of 7.22 (being 4.24 times greater than the control sample) in terms of CBR strength.
A. Garg, Sanandam Bordoloi, S. Mondal, Jun Jun Ni, and S. Sreedeep 2020	To evaluate various compaction metrics, including California bearing ratio (CBR), and unconfined compression strength tests (UCS) on subgrade soil.	fibers with 10, 15, and 20 mm lengths.	With increasing fiber length and content, the California bearing ratio (CBR) and unconfined compressive strength (UCS) both rose significantly; at 15 mm fiber length and 1.5% fiber content.
N. Das and Shashi Kant Singh 2019	improving the subgrade soil strength.	Inclusion of palm fiber with lengths of 30mm to 35mm and percentages of 0.1% to 1.0% by the weight of soil.	Maximum density decreased as the fiber content increased while the ideal moisture content increased. With palm fiber inclusion, the maximum soaking CBR value was 14%, and the unconfined compression value was 352 kPa. These maximum values were discovered at the ideal 0.2% fiber content.
Nima EsmaeilpourShirvani, Abbasali TaghaviGhalesari, Mohammadreza Khaleghnejad Tabari, and Asskar Janalizadeh Choobbasti 2019	Aim of study was to evaluate the strength of subgrade of two types of clayey soil by adding jute fibers.	0.25% to 1.25% of jute fiber with an increment of 0.25% and a length variation of 0.5cm to 1.5cm.	Fiber of length of 1 cm with 0.75% fiber content showed an increase in both UCS and CBR values.
M. Olgun 2013	Fundamental characteristics were identified, including compaction characteristics, unconfined compressive strength, and California bearing ratio in both soaked as well as unsoaked circumstances.	The soft soil was combined with 25 mm long jute fiber in percentages ranging from 0.25% to 1.0% by weight of soil.	CBR strength of the sample was increased from 2.8% to 6.5% under soaked conditions.
C. Tang, B. Shi, W. Gao, F. Chen, and Y. Cai 2007	Improving the subgrade soil strength.	clayey soil with a range of 0.3% to 0.9% for jute fiber at a 6mm length.	Soft soil specimens with a length of 6 mm and a 0.6% fiber content demonstrated efficacy.
V.Saravana Selvam, M. Sivaraja, K. Raja, K.S. Navaneethan, and G.Dheeran Amarapathi 2016	To assess the hemp fiber-infused clay's strength parameters.	Clay sample mixed with fiber percentages varying from 0.5% to 1.5% with an increment of 0.25%. The length of hemp fibers was kept constant at 4cm.	undrained shear strength characteristics and were successful in providing that the strength of fiber-reinforced clay indeed increased from 0.5% to 1.25% and then decreased from then onwards.
Chao Sheng Tang, B. Shi, and Li Zheng Zhao 2010	To assess the black cotton soil's strength parameters using hemp fiber.	Hemp fiber and coir fiber in percentages of 0.1% to 0.4% by mass of black cotton soil treated with alkali-activated binder. Fiber was kept at 25mm.	Increased the resilience of soil fibers to freeze-thaw cycles.
Samer Rabab'ah, Omar Al Hattamleh, Hussein Aldeeky, and Bilal Abu Alfoul 2021	To assess the black cotton soil's strength parameters using hemp fiber.	Expansive soil subgrade incorporated with alkali-activated binder with the inclusion of fiber with percentages of 0.2% to 0.8%	Significant increase in CBR value was found.
Shahriar Shahrokhabadi and Najme Nazeryzadeh	Impact of bamboo fiber on clayey subgrade soil's CBR strength.	Bamboo fiber with varying percentages from 0.2% to 1.4% with an increment of	Thickness of the pavement will decrease due to this significant

2013		0.2%. the length of the fibers was selected to be 10mm and 20mm.	increase in CBR value
Sayyed Mahdi Hejazi, M. Sheikhzadeh, Sayyed Mahdi Abtahi, and A. Zadhoush 2012	Effect of bamboo fiber on CBR strength of clayey subgrade soil.	1% to 5% of fiber percentages to a problematic soil.	a tendency of all specimen compressive stresses to rise as the amount of bamboo fiber in them rose. Bamboo fiber content of 0%, 1%, 3%, and 5% had maximum compressive stresses of 115, 108, 130, and 152 kN/m2
M. Syed, Anasua GuhaRay, and D. Goel - 2022	The efficiency of incorporating kenaf fiber into clayey soil to improve its engineering behavior.	Percentages representing 0.25%, 0.50%, and 0.75% of the soil sample's weight.	Fibers had a stronger impact on improving soil mixture ductility than clay content did.
Pradip Kumar Pradhan, Rabindra Kumar Kar, and A. Naik 2012	Strength and mechanical properties of silty sand reinforced with short resinous Polypropylene (PP) fibers arranged at random.	Fibers of percentages; 0.25% to 0.75% of the weight of soil and in lengths of 1.5cm, 2cm, and 3cm.	The strength of the reinforced soil significantly increased with the addition of 1.5 cm fibers.
Prasad Dhammika Dharmaratne, Harsha Galabada, R. Jayasinghe, Renuka Nilmini, and Rangika Umesh Halwatura 2021	Improving the subgrade soil strength by the addition of PP fibers.	fiber lengths (6 mm, 12 mm, and 20 mm) and fiber content percentages (0.25%, 0.50%, 0.75%, and 1.0%).	For the 12 mm-long fibers, the highest strength values were obtained with a content of 0.5%–0.75%.
B. Mishra and Mohit Kumar Gupta - 2018	Improving the subgrade soil strength by the addition of PP fibers.	A fiber ratio of 0.4% to 0.8%	Proved maximum strength within a varying ratio of 0% to 1%.
R. P. Munirwan, Munirwansyah, Marwan, P.	Effectiveness on the subgrade soil's technical attributeswhen	proportions by soil weight that range from 0% to	produced a CBR value, a reduction in the plasticity
J. Ramadhansyah, and V. Kamchoom 2020	recycled polyethylene terephthalate (PET) fibers were incorporated with fly ash.	1.6% with a 0.4% increase.	index, and an increase in shear strength. It was discovered that 1.2% recycled PET fiber was the ideal quantity.
L. Peter, P. K. Jayasree, K. Balan, and S. Alaka Raj 2016	To ascertain how the strength behavior of clayey soil is affected by the polyester fiber content.	A set of unconfined compressive strength tests (UC) and consolidated undrained (CU) triaxial compression tests conducted on compacted, untreated, lime-treated, and cement-treated clayey soil specimens reinforced with varying weights of polyester fibers (i.e., 0%, 0.05%, 0.1%, and 0.2% by weight).	Found an increase in strength within the fiber contents from 0% to 0.2% by a factor between 2.3 to 4.6.
Sridhar Rajagopalaiah - 2019	To ascertain how the strength behavior of clayey soil is affected by the glass fiber content.	Random and discrete fiber glass with a percentage range of 0.25% to 1.0%.	Glass fibers significantly increase the UCS, and CBR values in subgrade soil while decreasing the free swell values.
Oğuzhan Yavuz Bayraktar and Kastamonu Üniversitesi 2020	To determine the effectiveness of Steel Fiber-reinforced Fly Ash and/or Cement-modified Marginal Soil (Clayey Sand).	Steel fibers with a diameter of 0.5 mm and lengths of 1 to 2 cm were employed.	4% by-volume addition of steel fibers was made to the marginal soil which increased its strength parameters.

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2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

Strength and Ductility Assessment Method for Elevated RC Water Tanks

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***Abstract*—Failures of elevated water tanks subjected to earthquake forces have been reported from many parts of the world in the past. Yet, a large number of elevated water tanks in Sri Lanka have not been designed for possible earthquakes whether they are minor or moderate in magnitude. When Intze type water tanks are considered, a huge mass is concentrated on top of the cylindrical shaped supporting structure. Therefore, this kind of structures can be conveniently modelled as a single degree of freedom system. In this study, pushover analyses were conducted using three-dimensional finite element model to develop bilinear load-deformation model based on equivalent energy criterion. With the developed bilinear model, nonlinear time history analyses of equivalent single degree of freedom system were conducted to obtain displacement demands. The variation of displacement demands of 72 cases covering different tank heights, capacities, shaft reinforcement ratios are presented.**

Keywords—Nonlinear time history analysis, nonlinear pushover analysis, lateral displacement, displacement demand

I. INTRODUCTION

Sri Lanka is generally considered to be located in an earthquake free region. However, recent ground shaking events occurred in and surrounding areas of the country alarmed the seriousness of consequences if unexpected ground shaking occurs in the country in future. Sri Lanka has vast number of elevated water tanks situated in whole parts of the island. The elevated water tanks are highly vulnerable even to a minor earthquake owing to their intended use. When subjected to earthquake loads elevated water tanks can fail due to various types of structural failures. Many such failures have been reported around the world. Yet, many elevated water tanks in Sri Lanka have not been designed even for possible minor earthquake loads. The dynamic behaviour of these structures significantly differs from that of static loads and needs careful and thorough analysis if seismic design provisions are to be imposed in design codes.

Elevated water tanks had poor and occasionally catastrophic seismic performance during many past severe earthquakes in many countries in the world. Number of research studies investigating the non-linear seismic response of Reinforced Concrete (RC) elevated water tanks have been conducted in the past. The response depends on many factors such as geometry and dimensions of the tank, water level (i.e., fully-filled, partially filled or empty), fluid-structure interaction, soil-structure interaction, magnitude and duration of the ground shaking. When partially-filled tanks are considered, modelling should be done by incorporating dynamic effects due to sloshing. Two mass models proposed by Housner [1] was one of the first models that include impact loads due to sloshing of water. This model has been commonly used in the most of the international codes. The main feature of this model is that the pressure generated within the fluid due to the dynamic motion of the tank was separated into impulsive and convective parts. When a tank containing liquid with a free surface is subjected to horizontal ground motion, both the tank wall and liquid subjected to horizontal acceleration. The liquid in the lower region of the tank behaves like a mass that is rigidly connected to the tank wall. This mass is called impulsive mass which accelerates along with the wall and induced impulsive hydrodynamic pressure on the tank wall. The liquid mass in the upper region of the tank undergoes sloshing motion. This mass is termed as convective mass and exerts convective hydrodynamic pressure on the tank wall. The base shear and overturning moment of tank structures can be determined using this model.

Algreane et al. [2] studied the fluid structure interaction due to dynamic response of elevated concrete water tank. In this study, the impulsive mass was divided by several numbers and attached along the circumference of the cylindrical wall at the level of the centre of gravity of the empty container. It was concluded that the suggested method of adding impulsive mass to the walls of tank does not affect significantly the dynamic behaviour of elevated tanks, both of the circular and rectangular shapes.

Early work by Epstein [3], Edwards [4], and Veletsos [5] conducted further studies on seismic design and dynamic analysis of liquid filled tanks by considering factors like tank flexibility and hydrodynamic forces. The effects of wall flexibility, soil-structure interaction, and sloshing motion on behavior of tanks subjected to ground accelerations were studies using techniques such as finite element analysis and computational fluid-structure interaction techniques.

Moslemi et al. [6] modelled liquid filled water tanks using finite element technique and both time history and modal analyses were carried out. Fluid domain was modelled using displacement based fluid elements and tank wall flexibility and sloshing effects were incorporated in the analysis. The complexities associated with modelling of conical tanks were also discussed.

In Intze type water tanks a huge mass is concentrated at top of the cylindrical shaped concrete supporting structure. Therefore, the structure can be modelled as single degree of freedom (SDOF) system by incorporating accurate stiffness and damping of the supporting structure. The main objective of this study is to establish a simplified but reliable and accurate analysis procedure to assess the safety of existing elevated water tanks subjected to horizontal ground accelerations. The proposed analysis is based on the concept of equivalent SDOF system in which the stiffness is computed using pushover analysis of water tank using three dimensional finite element model. Material models incorporating material nonlinearity of both reinforcements and concrete are employed in the pushover analyses. With this technique, highly computationally expensive and complicated dynamic analysis of multi-degree-of freedom systems (MDOF) can be converted to simple yet reliable SDOF systems while saving significant computing time.

II. Methodology

The proposed method consists of several steps as shown in Fig. 1. As the first step, pushover analysis of selected water tank is conducted using three-dimensional finite element model which consists of elements representing concrete and reinforcement bars. Then, a bilinear lateral load–lateral deformation model is established from the pushover curve. Two slopes of the bilinear model, k_1 being the initial slope and k_2 being the slope at the inelastic range are decided by fitting two straight lines to the visible two parts of the pushover curve based on the equivalent energy criterion (i.e., areas enclosed by the original curve and the two straight lines are equal), as shown in Fig. 2. The bilinear model will be used to determine required stiffness (K_{eq}) at different displacement levels in solving equation of motion of equivalent SDOF system given in (1). The equivalent mass (M_{eq}) is computed from the volume of concrete and water as appropriately for fully-filled and empty conditions. Equivalent damping (C_{eq}) is assumed to be 5%. The term $\ddot{u}_g$ is the ground accelerations of particular earthquake record and u, $\dot{u}$, and $\ddot{u}$ are the displacement, velocity and acceleration of the mass, respectively.

$$M_{eq}\ddot{u} + C_{eq}\dot{u} + K_{eq}u = -M_{eq}\ddot{u}_g \quad (1)$$

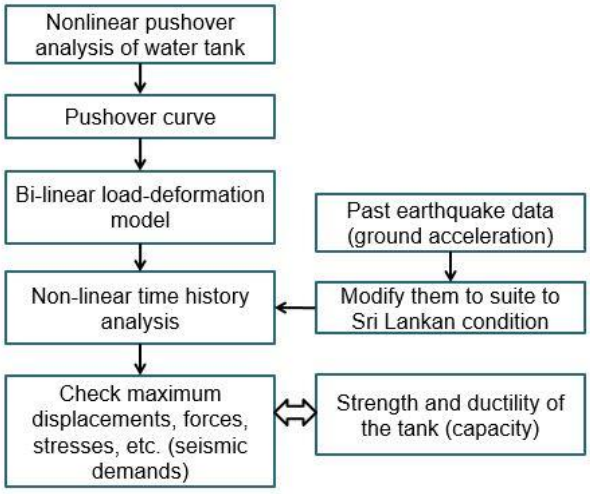

Fig. 1. Flow chart of the procedure

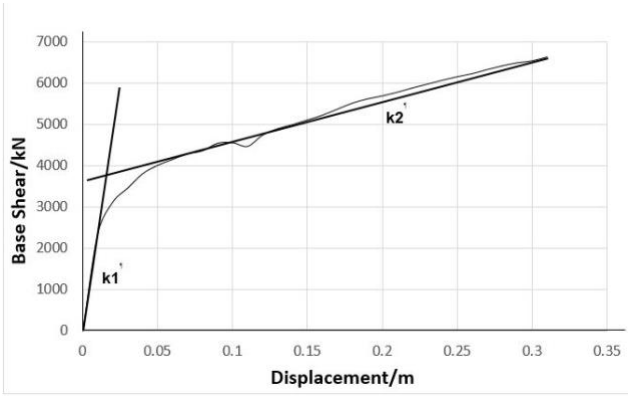

Fig. 2. Bilinear model of pushover curve

Past ground accelerations data can be downloaded from the available databases such as PEER. It is important to modify these acceleration records to suit with Sri Lanka condition. Then, the corresponding equation of motion of the equivalent nonlinear SDOF system is solved to obtain the maximum lateral displacement, base shear and other interested quantities. These quantities (demands) can be compared with the relevant capacities to check the safety of the tank.

A. Finite Element Model

In order to conduct nonlinear pushover analysis, finite element models are developed for the selected elevated tanks using MidasFea program [7]. Concrete segments are modelled using 8-node hexahedral elements and reinforcement bars by link elements. Two tanks of capacity 1200 m^3 and 750 m^3 that have been already constructed in Jaffna peninsula, are considered for the analysis. Element meshes of several components of the model are shown in Fig. 3. To be in the conservative side with respect to displacements, soil structure interaction was not incorporated into the analysis. As such, the base of the tank is assumed to be fixed. Two extreme cases, fully-filled and empty conditions of the tanks are considered in pushover analysis. Accordingly, the weight of the water mass is applied as point loads along the circumference of the top of the supporting cylinder. The self-weight of concrete and steel parts are incorporated to the model by assigning respective densities.

In nonlinear time history analysis, the liquid in the tank is modelled as a single mass with impulsive component of the water mass. This is a conservative assumption because the contribution of sloshing mode has been found to generate lower total response comparing to ignoring it [6].

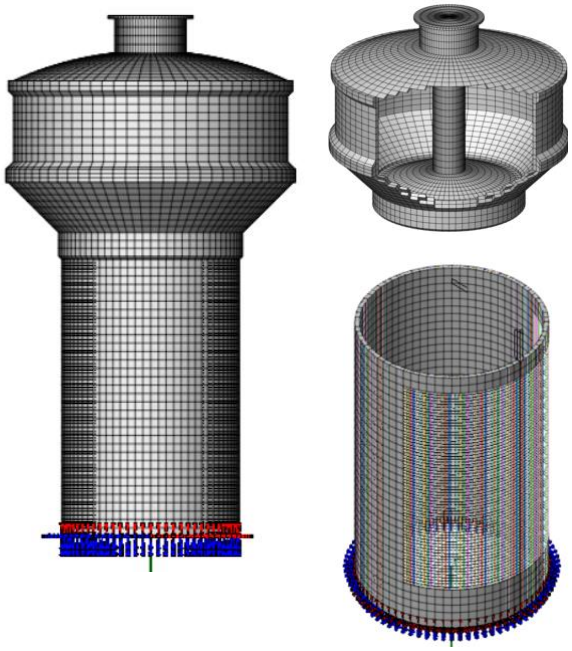

Fig. 3. Views of concrete and steel element meshes

B. Material Models for Steel and Concrete

Constitutive models representing the behaviour of reinforced concrete after cracking can be classified mainly into two models as discrete crack model, which is also called discontinuous model, and a smeared crack model. Furthermore, the smeared crack model can be classified basically into two models such as a decomposed-strain model and a total strain model depending on the numerical analysis methods adopted to simulate cracks. In MidasFea, the total strain crack model which is classified under the smeared crack model to predict the behaviour of reinforced concrete elements is available. In this study, total strain crack model with configuration of fixed crack model including secant stiffness, lateral crack effect and confinement effect, is used. The tension softening and compression behaviour of reinforced concrete material are represented by Hordijk and Thorenfeldt models [8]. For inelastic behaviour of steel, Von Misses yield criterion with kinematic strain hardening model is employed. The steel parameters are computed using a bilinear stress-strain curve.

C. Modified Ground Acceleration Records

Ground acceleration records are essential in order to conduct nonlinear dynamic analyses of the structure. There are three types of accelerograms namely; (1) Artificial accelerograms, (2) Natural accelerograms and (3) Simulated accelerograms. Analyses using simulated accelerograms are fairly complex to be implemented as they require a large number of input parameters and a comprehensive knowledge of the seismotectonic setting of the area under study. Therefore, this study uses real accelerograms for the dynamic analysis as real seismic input has the important advantage to account for amplitude, frequency content, energy content and duration characteristics of the real ground shaking. The above dynamic characteristics are very important in the assessment of nonlinear response of structures. The original time histories are scaled to match with the reference response spectrum of return period of 475 years proposed by Uduweriya et al. [9]. As per [9], the Peak Ground Acceleration (PGA) across Sri Lanka is in the range of 0.05–0.1g for the 475-year return period event and in the range of 0.07–0.3g for 2475-year return period event. In order to set PGA at 0.1g, the 475-year return period was selected in this study to predict the displacement demands.

III. Results

A. Nonlinear Pushover Analysis

Tanks with two capacities, 1200m^3 and 750m^3, each having three different heights (21.425 m, 16.425 m, 11.425 m) were considered in the analysis. The geometry and the dimensions of the tanks are as per the construction drawings of the tanks. For each height, six cases having six longitudinal reinforcement ratios, as presented in Tab. 1 and Tab. 2, were used. It should be stated that reinforcement ratios of 0.318 (Tab. 1) and 0.309 (Tab. 2) are corresponding to 10 mm bar size as per the original design values for 1200m^3 and 750m^3 tanks, respectively. The rest of the ratios are corresponding to bar diameters of 12, 14, 16, 18 and 20 mm. These bar diameters were decided by gradually increasing the design value of 10 mm bar diameter in order to check the effect of reinforcement ratio on the pushover curve and on the displacement, demands. As a result, there were 36 three dimensional finite element models created using MidasFea for each of fully-filled and empty tank conditions. Thus, altogether 72 pushover analyses were conducted and the corresponding bilinear load-displacement models were developed. These bilinear models were then used in time history analysis of equivalent SDOF systems.

TABLE I. DETAILS OF 1200M^3 TANK MODELS

Model No	Shaft Height/m	Tank Diameter/m	Longitudinal R/F Ratio
A1	21.425	16.5	0.318
A2			0.458
A3			0.623
A4			0.814
A5			1.030
A6			1.272
A7	16.425	16.5	0.318
A8			0.458
A9			0.623
A10			0.814
A11			1.030
A12			1.272
A13	11.425	16.5	0.318
A14			0.458
A15			0.623
A16			0.814
A17			1.030
A18			1.272

TABLE II. DETAILS OF 750M^3 TANK MODELS

Model No	Shaft Height/m	Tank Diameter/m	Longitudinal R/F Ratio
B1	21.425	14.9	0.309
B2			0.445
B3			0.606
B4			0.792
B5			1.002
B6			1.237
B7	16.425	14.9	0.309
B8			0.445
B9			0.606
B10			0.792
B11			1.002
B12			1.237
B13	11.425	14.9	0.309
B14			0.445
B15			0.606
B16			0.792
B17			1.002
B18			1.237

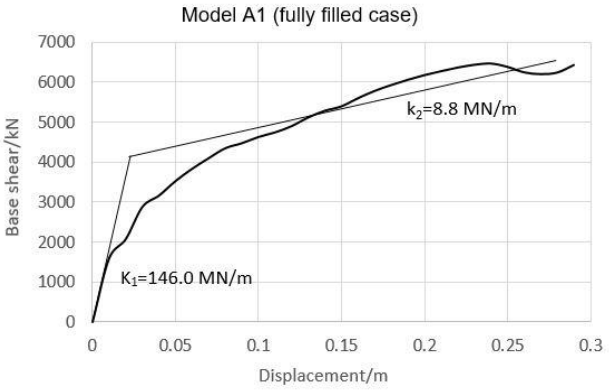

Fig. 4. Pushover curve and bilinear approximation for model A1 (fully-filled condition)

Tab. 3 and 4 contain k_1 and k_2 values obtained for 1200m^3 and 750m^3 tanks under fully-filled conditions. Results were obtained for empty conditions as well.

TABLE III. STIFFNESS VALUES OF FULLY-FILLED 1200M^3 TANKS

Model No	k_1 kN/m	k_2 kN/m
A1	146,786	8,836
A2	167,143	10,950
A3	202,727	7,383
A4	227,083	7,422
A5	244,074	7,103
A6	286,400	8,382
A7	182,951	12,015
A8	242,632	11,066
A9	285,476	9,844
A10	358,462	9,259
A11	417,714	12,961
A12	488,333	12,013
A13	259,504	20,679
A14	316,923	11,136
A15	380,905	10,009
A16	434,634	8,650
A17	498,020	6,488
A18	556,190	7,471

TABLE IV. STIFFNESS VALUES OF FULLY-FILLED 750M^3 TANKS

Model No	k_1 kN/m	k_2 kN/m
B1	73,453	5,152
B2	138,333	8,152
B3	191,111	7,629
B4	219,750	6,022
B5	260,302	6,234
B6	294,762	6,402
B7	124,722	9,304
B8	210,278	9,777
B9	261,667	8,382
B10	321,143	8,265
B11	356,865	7,947
B12	393,716	9,888
B13	179,464	17,509
B14	270,885	9,425
B15	328,684	8,419
B16	397,872	8,429
B17	466,944	9,146
B18	520,225	9,232

B. Non-linear Time History Analysis

For nonlinear time history analyses, one horizontal components of seven earthquake records, namely (1) Cape Medecino-1992, (2) Chi-Chi-1999, (3) Friuli Forgaria-1976, (4) Kobe-1995, (5) Colinga USA-1994, (6) Palm Springs-1986, and (7) Cocaeli Italy-1999, downloaded from PEER database, were considered. First, the acceleration values of each record were modified to match with Sri Lankan condition based on response spectrum proposed by Uduweriya et al. [9]. Then, averaged accelerations of these seven earthquakes were used in the analyses. Both water mass and tank mass were considered for fully filled condition while only tank mass was considered for empty tank condition. Maximum displacements obtained from the analyses are listed in Tab. 5 and Tab. 6, respectively for 1200m^3 and 750m^3 tanks.

TABLE V. DISPLACEMENT DEMANDS OF 1200M^3 TANKS

R/F ratio	Displacement/mm (Empty Tank)		
	h=21.425 m	h=16.425 m	h=11.425 m
0.318	579	353	238
0.458	540	377	234
0.814	425	211	104
1.272	311	112	62
	Displacement/mm (Fully-Filled Tank)		
0.318	532	329	220
0.458	513	269	232
0.814	426	199	106
1.272	298	105	61

TABLE VI. DISPLACEMENT DEMANDS OF 750M^3 TANKS

R/F ratio	Displacement/mm (Empty Tank)		
	h=21.425 m	h=16.425 m	h=11.425 m
0.309	610	414	247
0.445	563	398	236
0.792	413	239	93
1.237	270	137	59
	Displacement/mm (Fully-Filled Tank)		
0.309	570	385	239
0.445	516	366	214
0.792	388	222	89
1.237	248	129	62

The variation of maximum displacement with reinforcement ratios for 1200m^3 and 750m^3 tanks under fully-filled and empty conditions are shown in Figs. 5 to 8. It is clear from these figures that when reinforcement ratio increases the displacement demand decreases linearly. The rate of decrease is much higher in empty tank condition than the fully-filled condition.

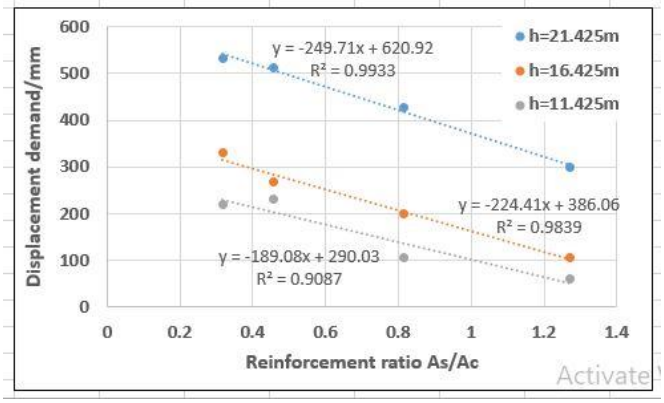

Fig. 5. Displacements vs reinforcement ratio of 1200m^3 tank (fully-filled)

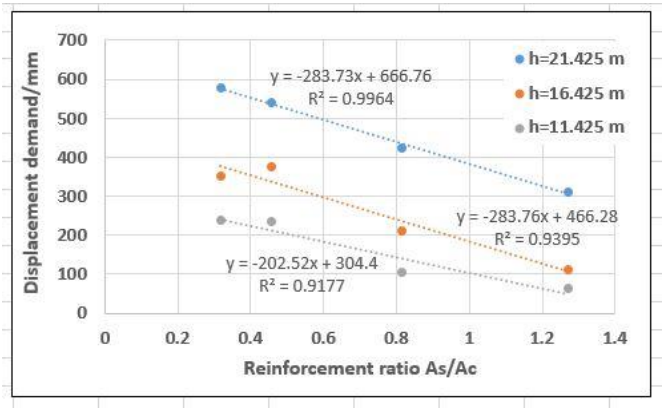

Fig. 6. Displacement vs reinforcement ratio of 1200m^3 tank (empty)

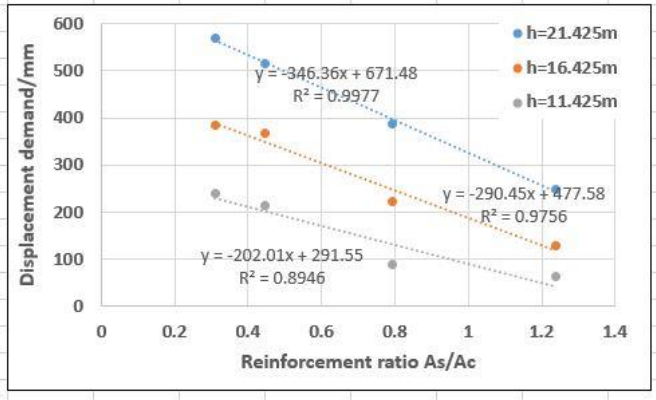

Fig. 7. Displacement vs reinforcement ratio of 750m^3 tank (fully-filled)

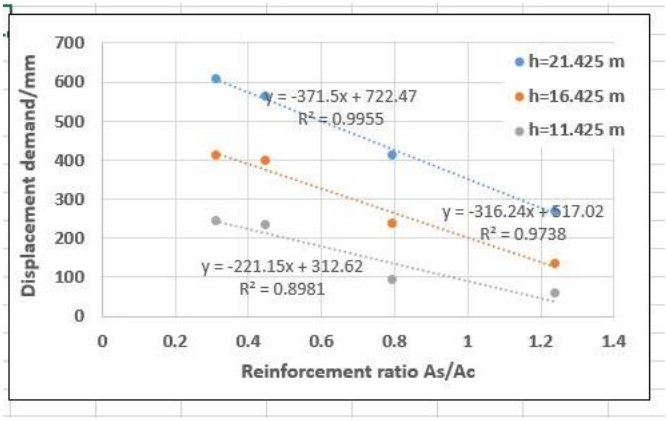

Fig. 8. Displacement vs reinforcement ratio of 750m^3 tank (empty)

IV. CONCLUSION

In this study, two capacities of tanks (1200m^3 and 750m^3), three cases of tank stem heights (21.425m, 16.425m, and 11.425m), six types of longitudinal reinforcement ratios, and two tanks conditions (fully-filled and empty tanks) were considered as variables in the analysis. Pushover analyses of 72 cases of elevated Intze type concrete water tanks were carried out using three-dimensional finite element models incorporating both steel and concrete nonlinear material behaviour. Using the pushover curve, bilinear load deformation models for each case was obtained and was used in nonlinear time history analyses using equivalent single degree of freedom sustems. The following can be drawn as the conclusions of this study;

(1) The proposed time history analysis procedure was found to be very computational efficient because it reduces a large number of degree of freedoms associated with three-dimensional modelling into an equivalent single degree of freedom system.

(2) The nonlinear lateral load-displacement behavior of elevated water tanks can be effectively incorporated into the SDOF system through the proposed bilinear load deformation models.

(3) When longitudinal reinforcement ratio (i.e., bar diameter with constant spacing) increases the displacement demand decreases linearly.

(4) The decrease of displacement demand is higher when the tank is under empty condition compared to fully- filled conditions.

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2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

An Intelligent Approach to Identify Household Canine Dermatology

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***Abstract*—Skin diseases in pets are a prevalent concern, affecting up to 75% of their health conditions. Traditional diagnosis methods for these conditions can be challenging, costly, and time- consuming. Given the increasing use of technology in veterinary medicine, past researchers have explored deep learning methods as a potential solution to improve the diagnosis and treatmentof skin diseases in pets. This study aims to create an intelligent system for pet owners and veterinarians to simplify skin disease identification. The system combines a lightweight deep learning model using a Convolutional Neural Network (CNN) for image analysis with a question-based feature extraction algorithm based on expert consensus. It captures and processes skin disease images, generating predicted scores. These scores are combined with answers to six questions using a weighted scoring algorithm to make the final prediction. The system accurately identifies common pet skin diseases like ringworm, mange, dandruff, and yeast infection with a 93%–98% accuracy rate. Its benefits include saving time and money, ensuring pet health, and pro- viding timely and accurate diagnoses. This technology offers a lightweight, cost-effective, and efficient solution to the challenges of traditional diagnostic methods, promising improved pet care.**

***Keywords*—Artificial intelligence, deep learning, image processing, CNN, canine dermatitis**

I. Introduction

A. Overview

The skin is the body's largest and most visible organ and the anatomical and physiological barrier between the animal and the environment. It grants protection from physical, chemical, and microbiological injury, and its sensory components sense heat, cold, pain, itch, touch, and pressure. In addition, the skin is integrated with internal organ systems, thereby reflecting disease processes that are primary or shared with other tissues elsewhere. Skin diseases are one of the most common health concerns among animals, resulting in a weakened immune system once infected. Several clinical reviews have indicated that skin disorders make up a large proportion of small animal patients. It has been estimated that from 20.00% to 75.00% of the cases seen in the average small pet have skin problems as a chief or concurrent owner complaint [1]. In this study, we analyze dermatological diseases associated with dogs because of their close relationship with their owners and the ready availability of data for analysis. Various types of skin diseases common among dogs can be classified as curable and incurable.

Among the curable ones, diseases such as dandruff, yeast infection, allergic dermatitis, and ringworm are often encountered on the epidermal layer of dogs' skin [2]. This study aims to develop a skin disease identification deep learning model with domain knowledge-based weighted scoring algorithms for household dogs. The proposed intelligent system intends to cater to innovations in dermatology diagnostic procedures to meet animals' physical and mental well-being, which are growing global concerns. Through this study, we can predict the disease based on a clear image of the dog's skin disease and some additional information from the dog owner. The proposed deep learning model and the algorithm will extract the features of the image given as input and identify if it belongs to one of the diseases mentioned above. In the end, accuracy and severity will be providedconsidering the output of the process diagnosis.

B. Background and Significance

The health of animals, whether livestock or pets, is inextricably linked to the well-being of people and the planet, meaning better animal health plays an integral role in sustainability. Surveys conducted in many countries show thatthe population of dogs as pets is increasing rapidly [3, 4]. Parallel to this increase in the dog population, the various diseases associated with them spread swiftly. Studies [5] and [6] show that skin diseases are prominent among them. When a pet gets sick or shows abnormal behavior, normally the owner is required to visit clinics and contact a doctor. There are no other options because of the knowledge gap and difficulties in understanding. Considering the above factors, veterinary doctors get a significant percentage of daily skin disease cases [7]. Pet owners have to spend high costs here, and pets take longer to recover. Even doctors may find distinguishing diseases with similar clinical signs challenging through a general test. As a result, one has to resort to advanced tests to differentiate the diseases, which takes time and can be inaccurate. A solution to the points mentioned above is an intelligent algorithm to identify and predict the health issues of our pets and animals via visual inspection and data analysis. This solution lets the pet owner diagnose their dog's skin diseases without visiting the clinic and saves unnecessary expenses. Not only pet owners but also doctors can use this intelligent system to confirm their judgment in some cases. To validate the claims of this

study, Table I provides a comprehensive comparison between diseases based on the identified features. All these identified features are based on the knowledge of veterinary domain experts and previous studies [8, 9, 10, 11].

TABLE I
DISEASE COMPARISON

Disease Appearance	Disease			
	Dandruff	*Mange*	*Ringworm*	*Yeast infection*
Itchiness	✓	✓	✓	✓
Thickened Drie oily and greasy infected area				✓
A musty odor	✓			✓
Notice white flakes	✓			
Redness with roughlyred ring appearance			✓	
Red ring appearance Patches of hair loss and crusting		✓		

C. Related Works

Skin diseases are a common concern for pet dogs; early detection is vital for their well-being. Traditionally, veterinarians visually assess these conditions, which can be time- consuming and subjective. However, recent advances in deep learning and computer vision have spurred interest in creating intelligent systems to identify dog skin diseases accurately through images. In 2017, a research team proposed using deep learning to categorize dog skin diseases using multispectral imaging. They aimed to distinguish between bacterial dermatosis, fungal infection, and hypersensitivity allergic dermatosis. They gathered regular and multispectral images to build their model and employed four CNN model architectures: Inception, ResNet, DenseNet, and MobileNet. These models were trained on data from 15 species of 94 dogs, with data augmentationto enhance accuracy. The study reported moderate accuracy levels and Matthews Correlation Coefficients (MCCs) for eachdisease on the validation dataset. However, the researchers recommended incorporating a consensus approach to improve model performance. Subsequently, the same study showed that consensus models outperformed individual models, achieving higher accuracy and MCCs for each disease on the validation dataset [12]. In 2018, another study introduced an intelligent dog skin disease detection system, incorporating ontology- based clinical information extraction. This mobile application integrates disease identification, severity detection, domain- specific knowledge, and an AI-based chatbot for dog owners. It enhances its functionality by utilizing CNNs and Natural Language Processing (NLP) techniques. The researchers collected and processed images of ringworm, dandruff, and yeast infection, employing augmentation to expand the dataset. Several models were tested, with a model featuring a convolutional layer in a 2D pattern outperforming transfer learning with 98% accuracy. The study's future focus is expanding the system's capability to categorize additional skin conditions and assess severity levels using images and text data [13]. In 2019, researchers concentrated on three dog skin diseases: mange, ringworm, and fleas, using color pictures from clinical and online sources. They applied a CNN with three layers featuring 16, 32, and 64 output channels. The algorithm was trained on a dataset split into a training and validation set, and it generated images with skin disease labels. The model achieved a training accuracy of 82%, a validation accuracy of 55%, and a loss of 46% [14].

II. METHODOLOGY

Over the past few years, the use of deep learning techniques for detecting skin diseases in household dogs has grown substantially. The current study aims to contribute to this emerging field by developing a lightweight, intelligent system that combines deep learning models and domain knowledge algorithms. This system can accurately classify and identify various skin conditions in dogs while also being able to deploy on mobile platforms. To achieve this, the study followed a comprehensive methodology that included collecting and preprocessing data, designing the architecture, training the model, and evaluating its performance.

Integrating domain knowledge algorithms into the deep learning model helps to develop an intelligent system that offers an accurate and reliable diagnosis of skin conditions in dogs to veterinary professionals and pet owners. This can enhance the health and well-being of household dogs by making the diagnosis and treatment of skin diseases more efficient and effective. The proposed intelligent system is focused on detecting four skin diseases commonly found in dogs: ringworm, dandruff, yeast infection, and mange.

Identifying skin diseases in dogs in this study involves two critical steps. First, the user uploads an image of the infected area. Second, the user responds to a series of simple yes or no questions presented by the intelligent system. Using deep learning models and domain knowledge algorithms, the system analyzes the user's responses and the uploaded image to determine and communicate the specific skin disease afflicting the dog. This method provides an efficient and user-friendly approach to identifying common skin diseases in household dogs, which could enhance accuracy and speed of diagnosis.

A. Data Collection

To collect data for this study, a comprehensive approach was employed that involved collecting images of infected areas from various sources, including veterinary clinics such as Welisara Veterinary Hospital, Sri Lanka, and Peradeniya Veterinary Teaching Hospital, Sri Lanka, as well as past research papers [13]. Related information about each image, such as the type of skin disease and any relevant medical history, was also obtained from these sources. The collected data were then subjected to thorough quality checks and preprocessing to ensure its suitability for the deep learning model. Overall, this rigorous data-gathering process ensured that the resulting model was trained on a robust and diverse dataset capable of accurately identifying various skin diseases in household dogs.

B. Development Tools

As for the development library, TensorFlow was chosen as the primary tool for building and training machine-learning

models. As an open-source software library specifically designed for machine learning and deep learning applications, TensorFlow provides a flexible architecture and intuitive Application Programming Interfaces (APIs) for easy designing and training models while optimizing performance. Tensor- Flow's capacity to handle large datasets and scale models across multiple devices made it an obvious choice to implement the proposed algorithm.

C. Data Preprocessing

Identifying skin diseases from images entails several critical steps. The initial step involves accurately labeling the dataset, ensuring correct categorization for each distinct skin condition. This precise labeling is fundamental to training a dependable system. Following this, the images undergo preprocessing procedures, including techniques such as Laplacian sharpening, Gaussian smoothing, Sobel operator and Canny edge detection. Notably, the study revealed that using the following specific kernel 1 for image sharpening produced the most favorable outcomes regarding accuracy and effectiveness.

$$Kernel = np.array([[0, -1, 0] \\ [-1, 5, -1], \\ [0, -1, 0]]) \quad (1)$$

A common challenge is having an insufficient number of images for each disease. Data augmentation techniques, including rotation and flipping, were used to expand the dataset to a minimum of 250 images for each condition. Datasets are typically split into three parts: 70% for training, 20% for validation, and 10% for testing. This ensures practical model training, validation, and testing to assess performance without overfitting.

D. Proposed Algorithm

1) Skin disease classification model

This research aimed to create a mobile-friendly, lightweight expert system that utilizes deep learning models to classify disorders accurately. We employed five different CNN models and transfer learning approaches to categorize images into four classes to achieve this goal. We utilized different CNN architectures with varying layers to make it easier to select the best-performing lightweight model during the final implementation of the expert system. This approach improved the comparison of results and ultimately led to a more accurate disorder classification.

a) Vgg16
b) MobilenetV2
c) Squeezenet
d) Efficientnet
e) Cmax8net (CNN 2-dimensional pattern)

Vgg16, Efficientnet, Squeezenet, and Mobilenet are examples of lightweight transfer learning models that have been pre-trained on large datasets. In contrast, the 2-dimensional CNN model (cmax8net) used in this research was developed specifically for this study. The architecture of the proposed Cmax8net CNN model is presented in Fig1 the model has several layers, including four

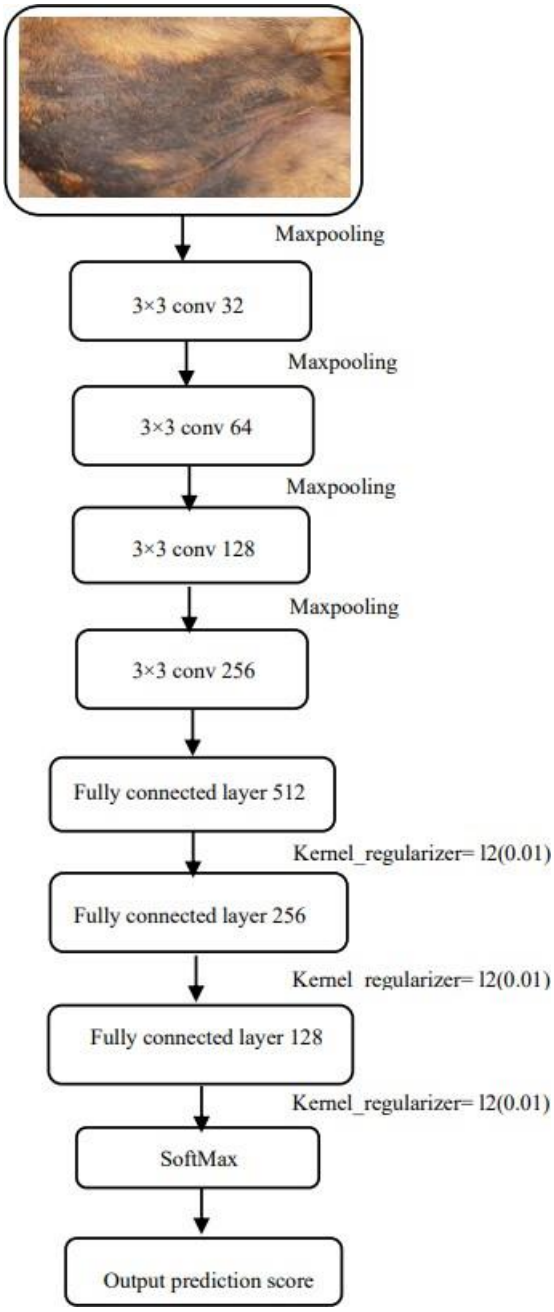

Fig. 1. Architecture of Cmax8net model.

convolutional layers, four max-pooling layers, and four dense layers. The first layer is a 2D convolutional layer with 32 filters, a filter size 3x3, and a rectified linear unit (ReLU) activation function. The input shape is specified as an argument in this layer. The second layer is a max-pooling layer with a pool size of 2x2. The following three convolutional layers have 64, 128, and 256 filters,

respectively, with the same filter size and activation function as the first layer. Each convolutional layer is followed by a max-pooling layer with the same pool size. The fully connected layers consist of a flattened layer and three dense layers with 512, 256, and 128 units, respectively, and a ReLU activation function. The regularization technique l2 regularization is applied to the second, third, and fourth dense layers with a regularization rate of 0.01. Finally, the last dense layer has four units and a SoftMax activation function to output the predicted probabilities of the input belonging to one of the four classes.

2) Weighted scoring algorithm

Identifying the presence of a disease in a dog requires a comprehensive diagnostic process that considers various factors, including the animal's external physical characteristics. To this end, a domain knowledge" weighted scoring algorithm" has been devised that relies on responses to six straightforward questions about the dog's physical attributes. The weighting of each question in the algorithm was generated based on input from veterinary professionals and internet sources, specifically regarding the questions' relevance to identifying the disease in question.

- A weight of 0.5 was assigned to questions that directly impact the diagnosis of the illness.
- While those that influence the diagnosis to a certain extent were given a weight of 0.2.
- The remaining questions were assigned a weight of 0.03.
- Respondents were provided with three response options:" a lot,"" a little," and" not at all," each of which was assigned a score of 1, 0.5, and 0, respectively.

Accordingly, the questions are as follows:

I Does your pet frequently itch from the infected area?
II Does the skin in the infected area look oily, greasy, thickened, and scaling?
III Do you feel a musty odor or a strange odor from the infected area?
IV Do you notice white flakes in the infected area?
V Are there any lesions that look roughly like a red ring?
VI Can you see patches of hair loss with scaling and crusting skin?

The weights given based on the domain knowledge for each question for each disease are shown in the following Tab. 2. Thus, a predicted score for each disease, the values associated with the responses provided by the respondent, are multiplied by the weights assigned to each question in the domain knowledge algorithm. The resulting products are summed to produce a domain knowledge predicted score for each disease. This process allows for a quantitative assessment of the likelihood of a particular disease based on the external characteristics of the dog, providing valuable insights to inform the diagnostic process. By leveraging the expertise of veterinary professionals and domain experts in developing this algorithm, the resulting predicted scores are more accurate and reliable, enhancing the quality of disease diagnosis in dogs. The predicted scores of a deep learning model and a domain knowledge algorithm are combined to enhance the accuracy of disease diagnosis in dogs. Specifically, the scores predicted by each method are weighted equally, with each contributing 50% to the final disease prediction. The disease with the highest predicted score, as determined by the combined scores from the deep learning model and domain knowledge algorithm, is ultimately considered the final diagnosis. This approach represents a valuable advancement in disease diagnosis, as it leverages the power of machine learning and the insights of domain experts to produce a more accurate and reliable prediction. Finally, when summarizing the methodology, the inputs and outcomes of each stage can be represented in a flow chart, referred to as Fig 2

TABLE II
WEIGHTS FOR EACH DISEASE

Skin Disease	Questions					
	QI	QII	QIII	QIV	QV	QVI
Ringworm	0.2	0.03	0.03	0.03	0.5	0.2
Mange	0.2	0.03	0.03	0.2	0.03	0.5
Dandruff	0.2	0.03	0.2	0.5	0.03	0.03
Yeast infection	0.2	0.5	0.2	0.03	0.03	0.03

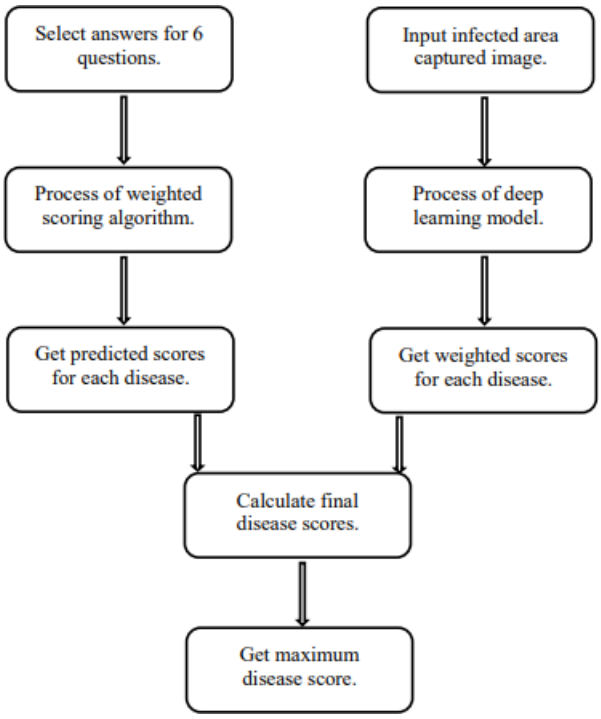

Fig. 2. Conceptual framework of the expert system

III. Results and Discussion

The study aims to develop a dog skin disease identification system using machine learning and domain knowledge-based weighted scoring algorithms. The primary objective is to create a lightweight, mobile-friendly system that assists veterinary professionals and pet owners in identifying four common skin diseases in dogs: ringworm, mange, dandruff, and yeast infection. The data collection process involves compiling a dataset of images and related information for each disease, which is then utilized to train and test the machine learning model. The weighted scoring algorithm is developed based on six questions and their relative importance for each disease. In this results section, we present the accuracy results obtained from both the machine learning model and the weighted scoring algorithm, as well as the final prediction and weight distribution used in the system.

A. Skin disease identification using infected images

The main objective of this study is to develop lightweight, mobile-friendly deep-learning models for skin disease identification utilizing CNNs. The study assesses transfer learning models, including Vgg16, Efficientnet, mobilenetv2, Squeezenet, previous study custom model [14], and a proposed model (cmax8net) based on the conv2d architecture. After augmenting the dataset, each model is trained using approximately 250 images per disease. The testing accuracy obtained for eachmodel is recorded and presented in Tab. 3.

TABLE III
Accuracy Table

Model	Accuracies
Custom model [14]	0.4700
Squeezenet	0.5600
Mobilenetv2	0.8515
Vgg16	0.9348
Efficientnet	0.9672
Cmax8net	0.9753

Analysis of the obtained accuracies presented in the table reveals significant findings. The mentioned Squeezenet model and conv2d model, which were proposed in a previous research study [14], yielded unsatisfactory results when trained on the current image dataset, exhibiting notably low accuracy. This suggests that those models may need to be better suited for the specific characteristics and complexities of the given dataset. The lower accuracy obtained highlights the need for careful consideration and evaluation of different models in the context of the dataset to identify the most suitable architecture for achieving better performance. The evaluated models, including Mobilenetv2, Vgg16, Efficient-net, and the proposed CNN model (Cmax8net), demonstrated impressive accuracy rates and were further improved through data augmentation techniques. Mobilenetv2, known for its lightweight and efficient nature, offers a compelling option for applications with limited computational resources. Efficientnet is also renowned for its lightweight nature and ability to achieve impressive accuracy on image classification tasks while maintaining high computational efficiency. It combines advanced scaling techniques with efficient network architecture design to deliver exceptional performance with minimal computational resources. In contrast, vgg16 is often favored in tasks that require high accuracy, such as image classification, object recognition, and fine-grained visual tasks. However, in terms of being lightweight and suitable for mobile platforms, the proposed model emerged as the frontrunner, offering a balance of accuracy and efficiency. Notably, the proposed cmax8net model's architecture is less complex than the other transfer learning models discussed, yet it achieves accurate predictions. The accuracy, which is further improved through data augmentation, could be refined by hyperparameter tuning.Specifically, a batch size of 128, 20 epochs, and a learning rate 0.0001 are selected as the hyperparameters. During training, the model exhibited significant progress, with the validation accuracy initially at 0.39 and gradually increasing to 0.98 after 20 epochs. Similarly, the validation loss shows a notable reduction from its initial high value to 4.456. The model's performance on the test data yields an accuracy of 0.9753 and a loss of 4.3080. When evaluated with external data, the model consistently produces highly accurate predictions, achieving testing accuracies ranging between 90% and 100% for each disease class.

In Fig 3, a confusion matrix is presented, which is a table displaying the counts of true positives, true negatives, false positives, and false negatives. This table is used to evaluate the performance of a classification model. In Fig 4, the accuracy graph of the Cmax8Net model is shown. This graph illustrates the model's accuracy.

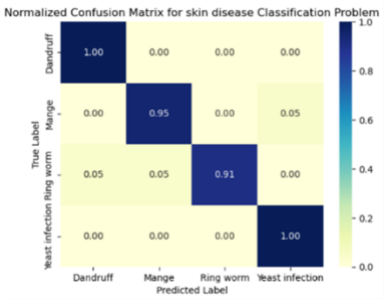

Fig. 3. Confusion matrix

B. Skin Disease Identification Using Weighted Scoring Algorithm

A scoring system has been developed to evaluate responses to six disease-related questions, taking into account weights and probabilities determined by experts and online sources. To determine the effectiveness of this system, a survey was conducted among 30 veterinary school students to assess its accuracy. The aim of the survey was to compare the students' answers to the established standards. The results for each disease are presented in Fig 5, Fig 6, Fig 7, and Fig 8.

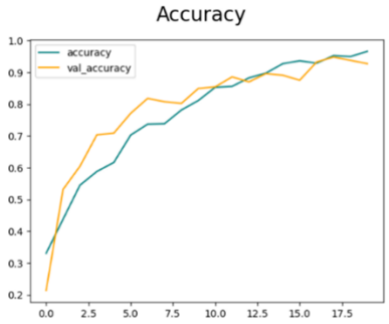

Fig. 4. Accuracy graph

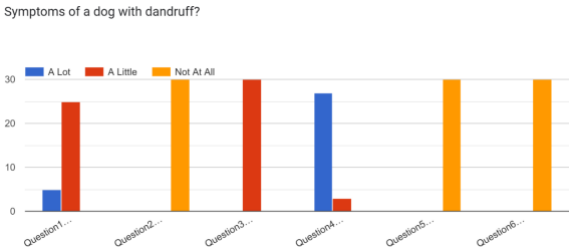

Fig. 5. Survey results in Dandruff

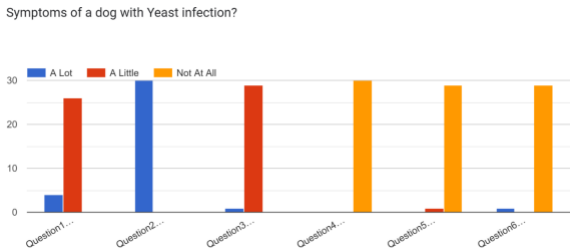

Fig. 6. Survey results in Yeast infection

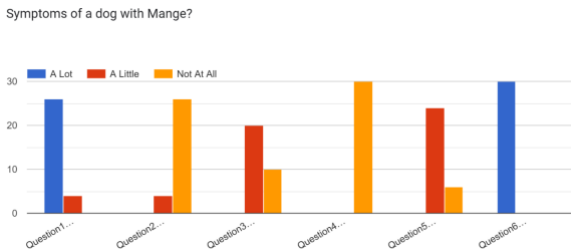

Fig. 7. Survey results in Mange

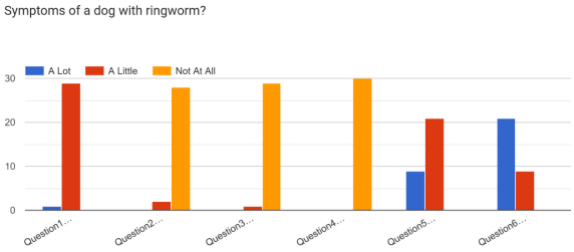

Fig. 8. Survey results in Ringworm

Based on the above graphs, the selected answers for each disease are calculated as a percentage and presented in Tab. 4, Tab. 5, Tab. 6, and Tab. 7.

TABLE IV
DANDRUFF AS A PERCENTAGE

Question	A lot (%)	A little (%)	Not at all (%)
I	16.6	83.4	-
II	-	-	100
III	-	100	-
IV	90	10	-
V	-	-	100
VI	-	-	100

TABLE V
YEAST INFECTION AS A PERCENTAGE

Question	A lot (%)	A little (%)	Not at all (%)
I	13.3	86.7	-
II	100	-	-
III	3.3	96.7	-
IV	-	1-	100
V	-	3.3	96.7
VI	3.3	-	96.7

TABLE VI
RINGWORM AS A PERCENTAGE

Question	A lot (%)	A little (%)	Not at all (%)
I	86.7.3	13.3	-
II	-	13.3	86.7
III	-	66.6	33.3
IV	-	1-	100
V	-	80	20
VI	100	3-	-

According to the methodology described earlier, higher percentages are obtained for the" a lot" option in questions deemed crucial for identifying each disease. This implies that selecting" a lot" for a question with a higher weight would result in a higher predicted score for that particular disease, indicating a correct prediction. Consider the example of dandruff: questions regarding the presence of white flakes, frequent rubbing of the affected area, and a strange smell are found to influence its identification significantly. The table

TABLE VII
MANGE AS A PERCENTAGE

Question	A lot (%)	A little (%)	Not at all (%)
I	3.3.3	96.7	-
II	-	5.6	90.4
III	-	3.3	96.7
IV	-	1-	100
V	30	70	-
VI	70	30	-

provided in the previous section shows that a very high percentage of respondents selected" a lot" or" a little" for these three questions, while the percentage for" not at all" is 0. Consequently, this algorithm exhibits nearly 100% accuracy in identifying the presence of dandruff. Considering all diseases, the scoring algorithm achieves an accuracy rate close to 100% for each disease. In summary, the weighted scoring algorithm's effectiveness in predicting diseases is assessed based on the percentages of different response options, particularly the higher-weighted questions. In the final prediction process, both the image prediction score and the weighted scoring algorithm contribute equally, each carrying a weight of 50%. This unique characteristic significantly influences the weighted scoring algorithm's overall prediction. Notably, the weighted scoring algorithm consistently achieves a high accuracy rate, often nearing 100%. Consequently, even in cases where the image prediction may result in misclassifications, the weighted scoring algorithm effectively corrects them. In recent studies [13], it is also mentioned that beyond the captured image, it is valuable to make a final prediction based on the behavior and characteristics of the pets. Therefore, that novelty part occupies a special place in this study.

C. Conclusion and Future Work

Skin diseases in household pets, especially dogs, are a prevalent and concerning issue that can cause various health problems. Unfortunately, conventional diagnosing of these conditions is often burdensome, costly, and time-consuming. Recognizing this challenge, researchers have explored deep learning techniques to improve the accuracy and efficiency of diagnosing and treating skin diseases in pets. This study aims to develop a lightweight and mobile-friendly intelligent system that combines deep learning methods with a weighted scoring algorithm based on domain knowledge. The objective is to provide a simplified approach for identifying skin diseases that is accessible to both pet owners and veterinarians. The proposed intelligent system leverages CNN models and a feature extraction algorithm based on a series of questions to detect skin diseases in pets accurately. The system generates predictive scores by inputting images into the deep learning models. These scores are then combined with the results obtained from answering specific questions using a weighted scoring algorithm. The final prediction is determined by considering the scores derived from both the deep learning models and the weighted scoring algorithm. On mobile platforms, this study's results showcase the system's effectiveness in accurately predicting common skin diseases in pets, including ringworm, mange, dandruff, and yeast infection, with an impressive accuracy range of 93% to 98%. Implementing this mobile-friendly system offers several benefits, such as cost and time savings, improved pet health and well-being, and accurate and timely diagnosis and treatment of skin diseases. This intelligent system presents a promising solution for overcoming the challenges of diagnosing skin diseases in pets by addressing the limitations associated with traditional diagnostic methods. Based on the current study's findings and limitations, several suggestions for future work can be made:

I Expanding the data set by increasing its size, diversity, and quality, collaborating with multiple veterinary clinics, and collecting data from different geographical locations is recommended. This would improve the generalization and accuracy of the deep learning models used for diagnosis.

II The skin diseases the system covers should be expanded beyond the existing four (ringworm, mange, dandruff, and yeast infection) to include more common types found in dogs. Developing a mobile application or device that enables real-time image capture and analysis would facilitate the immediate diagnosis and tracking of skin conditions.

III Collaborating with more veterinarians would provide valuable insights to validate and refine the system and contribute additional labeled data. Creating a user-friendly interface for pet owners and veterinarians, with clear instructions, visual aids, and explanations, is crucial. Regular updates to the deep learning models should be performed to incorporate new data and advancements in the field.

IV Exploring the integration of telemedicine capabilities would enhance accessibility and convenience for remote pet owners.

V User feedback surveys and evaluations should be conducted to improve usability, accuracy, and effectiveness.

Implementing these suggestions would contribute to developing a comprehensive expert system for identifying and diagnosing skin diseases in household pets.

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2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

Model Parallelism for Efficient GPU Computing in Deep Learning Applications: Comprehensive Review

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***Abstract*—This comprehensive analysis explores the transformative impact of parallel computing techniques in deep learning. It examines the collaborative endeavors of computer scientists and domain-specific researchers, encompassing a broad spectrum of strategies ranging from conventional data parallelism to cutting-edge methodologies like pipeline and inter-operator parallelism. By democratizing access to high-performance computing resources, these innovations are redefining the landscape of artificial intelligence (AI). The study highlights the considerable enhancements in training efficiency and model accuracy while addressing challenges such as integration complexities and ethical considerations. Additionally, the research investigates the environmental implications of large-scale parallel computing, underscoring the need for sustainable, long-term solutions to minimize its impact. It emphasizes the practical importance of these advancements, particularly in critical sectors such as healthcare and education, where AI-driven innovations hold the potential to revolutionize existing practices. Emphasizing a holistic approach, the analysis advocates incorporating ethical, environmental, and societal considerations in developing AI technologies. Envisioning a future where artificial intelligence is robust but also inclusive and sustainable, this analysis serves as a roadmap for fostering a more accessible, ethical, and environmentally conscious era of artificial intelligence. As the research community continues to push boundaries, this study guides the realization of responsible and impactful AI implementation.**

Keywords—Artificial intelligence (AI), data parallelism, inter-operator parallelism, parallel computing

I. INTRODUCTION

Deep learning methods face several challenges, including computational intensity, high memory requirements, and data parallelism bottlenecks, all of which impede the efficient training of large-scale models. Furthermore, issues such as communication overhead and scalability constraints limit the capabilities of existing deep-learning approaches. By introducing strategies such as parameter shading and task parallelism, model parallelism emerges as a solution to these challenges. The distribution of a model's parameters across different devices optimizes memory utilization and allows for the training of more complex models. In contrast, task parallelism divides computational tasks among devices, reducing the computational intensity of deep learning training. Hybrid approaches combining various parallelization techniques, dynamic computational graphs, and optimized communication all contribute to the effectiveness of model parallelism.

Examining the landscape of different parallel computing models exposes a complex tapestry of strategies and techniques that have transformed the computer industry. Executing several tasks or processes simultaneously is a fundamental idea known as task parallelism. It is frequently used in web servers to handle many concurrent user requests and in scientific simulations to decompose complicated issues into manageable pieces. Contrarily, data parallelism focuses on managing numerous data sets or components concurrently. It is essential in industries like image processing, where processes are evenly performed to individual pixels or frames for increased efficiency [1].

To improve the performance of current CPUs and GPUs, bit-level parallelism takes us deep within computer design fundamentals. Another architectural marvel, instruction-level parallelism, optimizes the execution of machine instructions, enabling contemporary microprocessors to carry out several instructions simultaneously and speeding up program execution [2, 3]. Task farming is widely used in rendering farms for computer-generated imagery (CGI) and distributed computing projects like SETI@home, where volunteers pool their computing capacity and distribute similar jobs among numerous processors or cores. Work is split into numerous phases using the pipeline parallelism method, allowing concurrent execution and data transmission. Digital signal processing and video encoding are applications where real-time data transformation and compression are necessary. Message passing and shared memory parallelism are used to meet the needs of several processes or threads for data exchange and communication [4, 5]. These techniques, which ensure synchronization and data consistency, are crucial in multiprocessor environments, distributed systems, and multithreaded applications.

The foundation of cloud computing, distributed databases, and scientific research initiatives that need significant computational resources is distributed computing, which scales processing over networks and involves several computers or nodes working together to solve complicated problems. Deep learning, scientific simulations, and a wide range of high-performance computing (HPC) jobs are just a few of the tasks that GPU computing finds widespread use in. GPU computing

harnesses Graphics Processing Units' parallel processing power [6, 7].

Choosing a particular parallel computing paradigm depends on several variables, including the task's nature, the available hardware infrastructure, and the required performance levels. The landscape of parallel computing, which enables the effective resolution of complex problems across various areas, is an example of its versatility, significance, and transformational impact on modern computing.

II. Literature Review

The necessity for considerable GPU resources, CPU parallelization, and Neural Network (NN) architectures in contemporary Machine Learning (ML) applications was covered by Goncharo et al. [8]. Due to its lack of multi-GPU training capabilities and adequate parallel CPU data preparation, the Ariadne library—created to solve challenging high-energy physics tracking issues using deep neural networks—faces a particular hurdle.

The authors explain their method for enabling multi-GPU training within the Ariadne library (see Fig. 1) in response to these difficulties. Their approach consists of several crucial elements: effective data caching, parallel CPU-based data preprocessing, and a general ML experiment structure designed for deep neural network model development, training, and inference. The authors also summarize their findings, highlighting the gains in speed and efficiency made possible by the GOVORUN computer resources.

This work improves the Ariadne library's capacity to handle challenging high-energy physics tracking problems by adding multi-GPU training and effective CPU parallelization. This work addresses the crucial need for scaling ML and NN applications.

A cutting-edge technology called PipeDream was created by Harlap et al. [9] to train Deep Neural Networks (DNNs) using GPUs. PipeDream uses a pipeline parallel computing architecture, which spreads computation over numerous computers, in contrast to conventional data-parallel training techniques. This method reduces the high communication-to-computation ratios from working with huge models or networks with limited bandwidth.

With PipeDream, communication overhead is significantly reduced compared to data-parallel training, with up to 95% reductions seen for big DNNs. Fig. 2 shows the high-level workflow of PipeDream. Additionally, it provides continuous processing and communication overlap, assuring maximum GPU utilization. PipeDream carefully allocates DNN layers across the available GPUs to balance workloads and reduce communication needs. Additionally, it uses parameter versioning for backward pass accuracy and round-robin scheduling for forward and backward passes on various inputs to enhance "*time to target accuracy*".

Using PipeDream with different DNNs on different clusters, experiments have shown how successful it is. Compared to conventional data-parallel training approaches, it has been discovered to be up to 5 times quicker in achieving goal accuracy. For large-scale deep learning applications, PipeDream offers improved efficiency, less communication overhead, and faster time-to-accuracy and is a significant development in DNN training.

The DNN training requires a lot of computing and might take days to weeks to finish. Parallel execution using Graphics Processing Units (GPUs) has been a popular strategy to speed up this training. The most common approach, data parallelism, is easier to implement but suffers from high inter-GPU communication costs because of frequent weight synchronization.

Pipelined model parallelism is an alternate strategy that divides the DNN model among GPUs to enable concurrent processing of several mini-batches. Compared to data parallelism, the method proposed by Chen et al. [10] lowers inter-GPU communication costs, but it still struggles with weight staleness. Gradients are calculated using out-of-date weights, which causes training instability and accuracy loss.

The pipelined model, the parallel execution strategy described in [10], maximizes GPU utilization while maintaining training accuracy. This is accomplished using a brand-new weight prediction method called "SpecTrain." Compared to data parallelism on a 4-GPU platform, experimental findings show that this strategy can achieve a tremendous speedup of increase to 8.91 times while maintaining a similar degree of model correctness. In conclusion, the suggested strategy addresses the trade-off between GPU utilization and training accuracy that afflicts current parallelization strategies and significantly improves DNN training efficiency.

Huang et al. [11] introduced GPipe, a novel pipeline parallelism library designed to address the challenge of efficiently scaling DNN capacity for various machine-learning tasks. Scaling up DNN capacity has proven effective in enhancing model quality but often necessitates specialized algorithms or infrastructure when the model size exceeds the memory limits of a single accelerator. These solutions tend to be architecture-specific and lack general applicability across different tasks.

Meanwhile, GPipe provides a practical and task-independent model parallelism solution. This is accomplished by scaling any network represented as a series of layers. Multiple sub-sequences of layers are distributed among various accelerators using GPipe's pipeline parallelism method. This architecture offers the adaptability to grow various networks quickly to much bigger sizes—the sequence of operations given in Fig. 3.

Its main innovation is the batch-splitting pipelining approach GPipe uses, which achieves almost linear speedup when dividing a model over several accelerators. The paper uses two unique projects with various network topologies to demonstrate the benefits of GPipe in practice.

1. Image classification: Using GPipe, an astounding 557 million-parameter AmoebaNet model is trained, and it uses the ImageNet-2012 dataset to achieve a top-one accuracy of 84.4%.
2. GPipe is used to train a single 6-billion-parameter, 128-layer Transformer model on a heterogeneous

corpus covering more than 100 languages for multilingual neural machine translation. This model performs better than all bilingual models, proving the value of GPipe for challenging, extensive multilingual jobs.

In conclusion, GPipe is a vital tool for enhancing the quality and capabilities of machine learning models since it provides a robust solution for effectively scaling deep neural network capacity across various workloads.

The methods for training huge transformer models that Shoeybi et al. [12] presented have shown considerable improvements in Natural Language Processing (NLP) applications. Large models, however, pose difficulties because of memory limitations. The authors of this study presented an effective intra-layer model parallel technique that makes it possible to train transformer models with a massive number of parameters. Notably, their method requires only a few communication operations within native PyTorch and may be easily implemented without requiring modifications to compilers or libraries. Pipeline model parallelism is opposed to and complemented by this method.

The authors demonstrate their methodology and impressive results by leveraging 512 GPUs to train transformer-based models with up to 8.3 billion parameters. Compared to a robust single GPU baseline that can handle 39 TeraFLOPs (about 30% of peak FLOPs), they can handle 15.1 PetaFLOPs of processing power throughout the application with 76% scaling efficiency. The researchers trained an 8.3 billion variable transformers language model (similar to GPT (Generative Pre-Trained Transformer 2)) version 2 and a 3.9 billion parameter model (similar to BERT (Bidirectional Encoder Representations from Transformers)) to show the impact of substantial language models. They emphasize the relevance of optimizing the layer normalization location as the model size grows in BERT-like models.

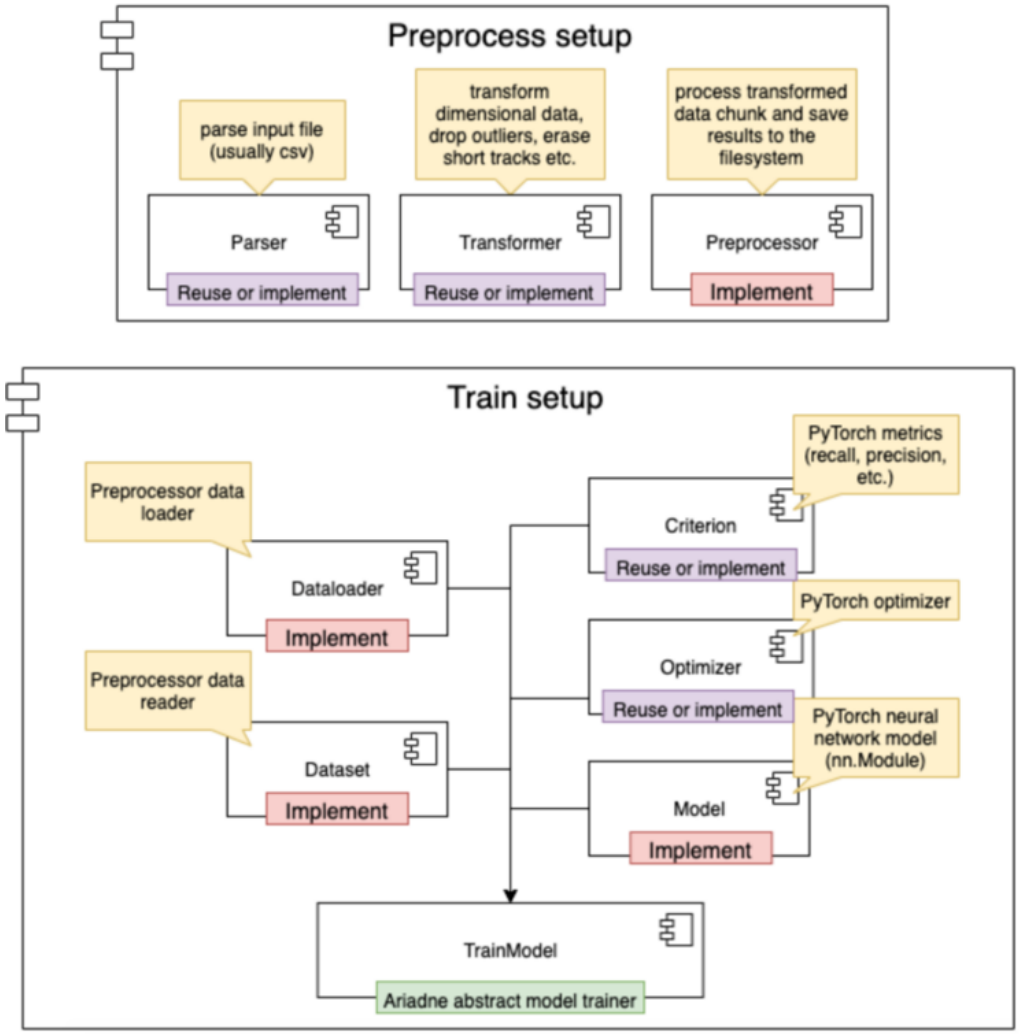


Fig. 1. Process setup and train setup of Ariadne API

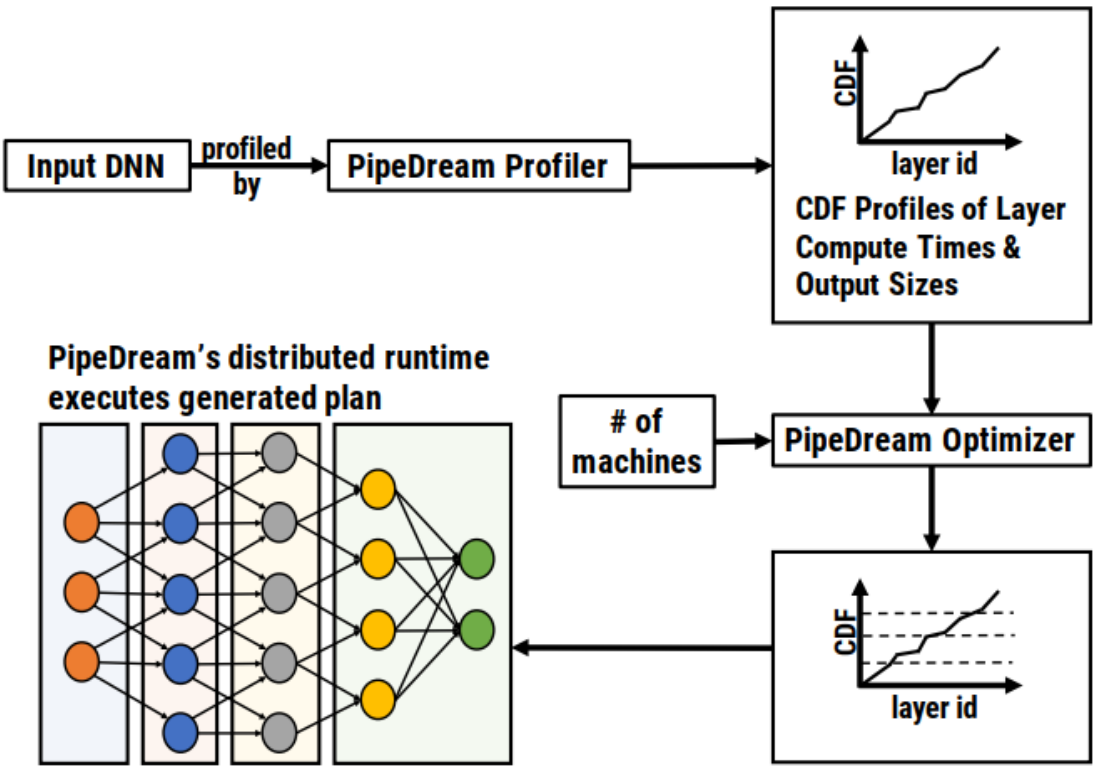


Fig. 2. Pipedream's automated mechanism to partition DNN layers into stages. pipedream first profiles the input DNN to get estimates for each layer's compute time and output size. Using these estimates, pipedream's optimizer partitions layers across available

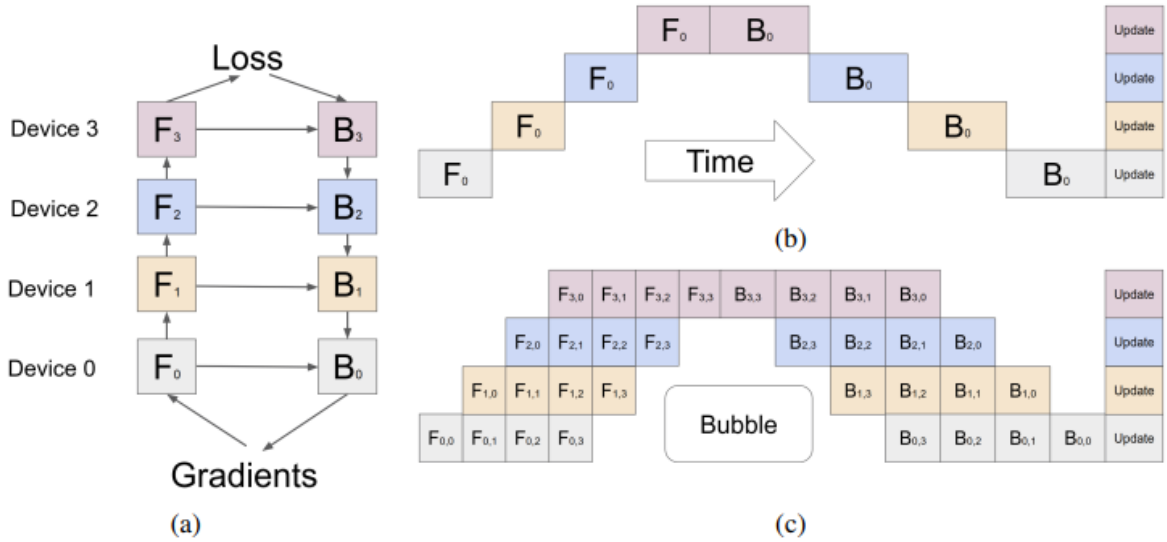


Fig. 3. (a) Illustrates a NN partitioned across four accelerators, (b) The inefficiency of the naive model parallelism strategy due to sequential network dependencies. (c) Introduces pipeline parallelism

On the WikiText103 and LAMBADA datasets, the authors produce cutting-edge results using the GPT-2 model, outperforming the prior best perplexity and accuracy scores. On the RACE dataset, their BERT model achieves advanced accuracy. In conclusion, the research provides methods for effectively training enormous transformer models, exemplifying their efficacy by excellent scaling and attaining cutting-edge outcomes on distinct NLP datasets. These developments may further improve the capabilities of huge language models in natural language processing.

The difficulties of training big DNN models, which have been expanding in size to increase accuracy and quality, were discussed by Park et al. in their study [13]. Such models frequently need to be trained to utilize a heterogeneous cluster of GPUs, including weaker GPUs unsuitable for training alone.

The authors respond to this problem by introducing HetPipe (Heterogeneous Pipeline), a DNN training method that combines data parallelism (DP) with pipelined model parallelism (PMP). In HetPipe, several GPUs create a virtual worker that executes minibatches in a pipelined manner.

Then, data parallelism is used by several virtual workers to improve performance further. The research also offers Wave Synchronous Parallel (WSP), a revolutionary parameter synchronization technique that supports both PMP and DP for virtual workers. Notably, the authors provide convergence evidence for WSP, guaranteeing the effectiveness and efficiency of the training procedure.

Fig. 4 depicts the architecture of the proposed H-node cluster system. Each node has a homogeneous set of GPUs, but the nodes' GPUs (and memory capacity) can be heterogeneous. The efficiency of HetPipe has been demonstrated by experimental findings in a diverse environment. HetPipe allows up to 49% quicker convergence of DNN models than state-of-the-art DP methods. This method significantly improves the effective training of large DNN models on heterogeneous GPU clusters. It enables using a range of GPUs, including less capable ones, to increase the speed and quality of model training.

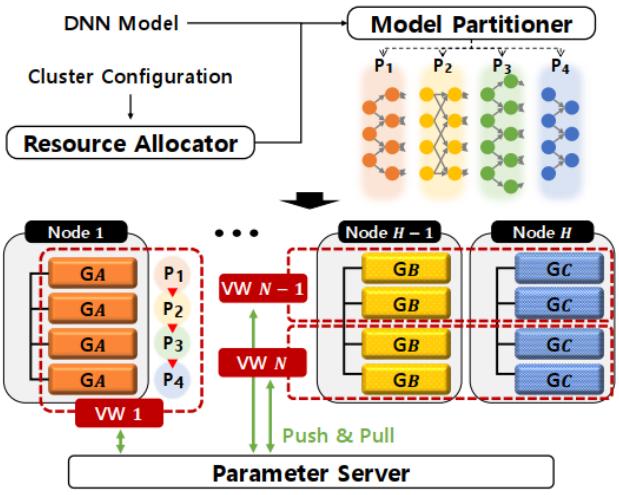
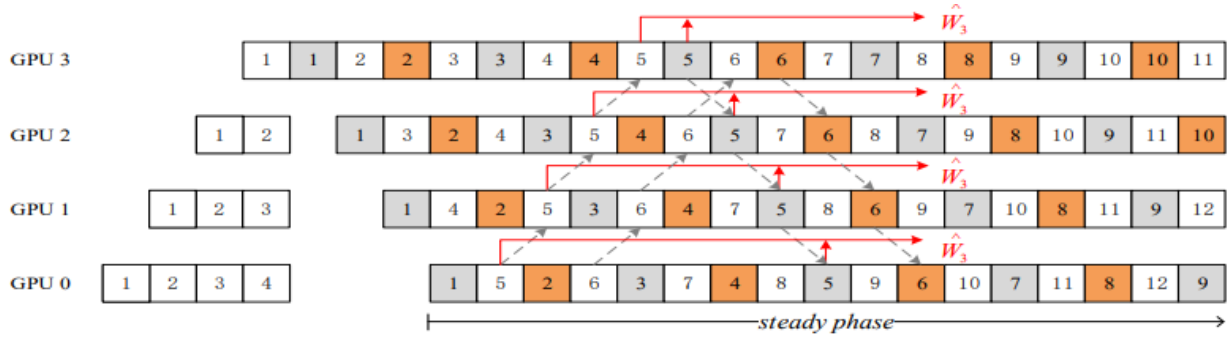
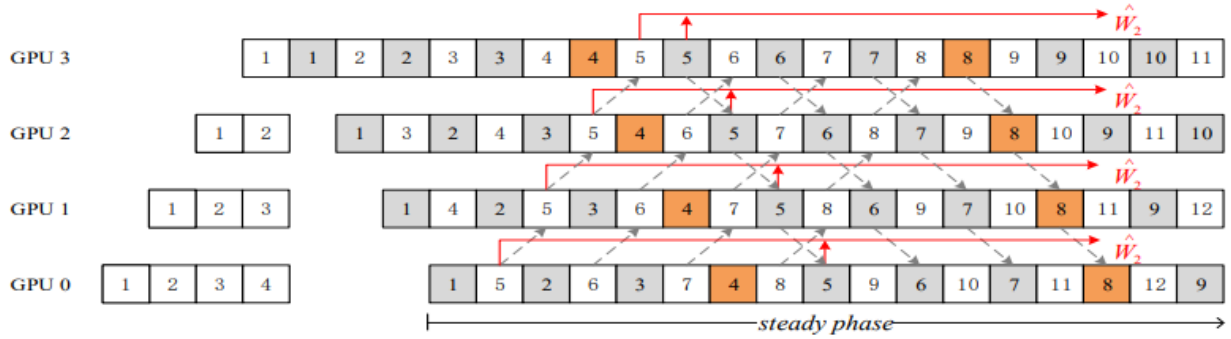


Fig. 4. The architecture of the proposed cluster system



(a) XPipe with $T = 2$



(b) XPipe with $T = 4$

Fig. 5. Illustration of Xpipe workflow on the 4-GPU system. Top: Xpipe workflow with micro batches = 2; Bottom: Xpipe workflow with micro batches = 4, *Adopted from [15]*

In distributed stochastic gradient descent (SGD) training of DNNs, the communication bottleneck problem was first addressed by Ström [14]. Due to the frequent necessity for synchronization of a model replica between compute nodes in data-parallel SGD, which results in a high communication cost, this issue emerges.

The suggested approach addresses this issue by purposefully regulating the rate of weight updates for specific weights inside the model. This differs from the conventional method, which imposes a consistent update rate based on the size of a mini-batch. According to the empirical data in the study, this approach can significantly reduce communication needs during the training of a standard DNN for tasks like acoustic modeling by as much as three orders of magnitude. This technology's decreased communication bandwidth enables scalability to more parallel GPU nodes more effectively than any other known approach. Surprisingly, this increased scalability is attained without compromising the DNN model's accuracy or convergence rate.

This method's noteworthy benefit is enabling training on commodity cloud networking and equipment, making it available and affordable. In conclusion, the study offers a novel approach to the communication bottleneck issue in distributed DNN training, notably lowering communication costs and enabling effective scaling while preserving model convergence and accuracy.

Guan et al. [15] present XPipe, a novel approach for optimizing pipeline model parallelism for training DNNs across multiple GPUs. By introducing an efficient and scalable pipeline model parallelism technique, the study addresses the challenges of scaling DNN training, particularly in the context of large-scale models. The workflow of the XPipe is shown in Fig. 5.

The authors introduce XPipe as a solution to improve the parallelization of DNN training across multiple GPUs in this study. The key innovation is the pipeline parallelism strategy, which divides and processes different segments of the neural network concurrently across various GPUs. XPipe optimizes this process by introducing efficient communication techniques, overlapping computation, and communication. XPipe significantly improves the training efficiency of large-scale DNNs by carefully managing pipeline stages and reducing communication overhead.

The paper provides a thorough technical analysis of the XPipe framework, detailing its architecture and the methodologies used for workload balancing, minimizing communication bottlenecks, and ensuring effective synchronization. The authors present experimental results demonstrating that XPipe outperforms traditional parallelization techniques. Extensive testing has revealed that XPipe achieves remarkable speedups in DNN training while retaining training accuracy, making it a promising solution for large-scale DNN applications. A comparison of HetPipe with other studies is given in Tab. 1.

GEMS [16], which stands for GPU-enabled memory-aware Model-Parallelism System, uses GPUs to address the challenges of large-scale DNN training by introducing memory-aware techniques. The authors' focus in this study is on improving the efficiency of distributed DNN training. They present GEMS as a solution that leverages the computational power of GPUs while keeping memory constraints in mind. The system employs novel model-parallelism techniques, allowing neural network models to be distributed across multiple GPUs. What distinguishes GEMS is its memory-aware approach, in which the system manages memory usage intelligently, ensuring optimal utilization of available resources without compromising performance.

The paper provides a detailed technical overview of GEMS, describing its architecture and the novel memory-aware methodologies used. These techniques allow GEMS to handle large-scale DNNs effectively, making it particularly useful for tasks requiring extensive computational resources and memory, such as deep learning applications in scientific research and artificial intelligence.

Furthermore, the authors present experimental results demonstrating the efficacy of GEMS. GEMS have significantly improved training efficiency and memory utilization in rigorous evaluations, making it a promising solution for accelerating distributed DNN training tasks. The researcher’s findings highlight GEMS’s valuable contribution to high-performance computing, particularly in large-scale machine learning applications.

A groundbreaking analytical model aimed at understanding the complexities of graphics processing unit (GPU) architectures was authored by Hong et al. [17]. The authors acknowledge the increasing importance of GPUs in modern computing and delve into the intricate interplay between memory and thread parallelism within these architectures in this study. They propose an analytical model that captures the nuances of GPU behavior by considering concurrent thread execution and parallel memory access processing. This model considers the dynamic nature of memory access patterns and thread execution, providing a more accurate representation of real-world GPU performance.

The components of their analytical model are meticulously described in the paper, including how it incorporates memory-level and thread-level parallelism awareness. By considering these two types of parallelism, the model provides a comprehensive understanding of GPU execution efficiency, shedding light on the factors that influence performance bottlenecks and throughput limitations.

The authors also validate their analytical model by comparing its predictions to empirical data from fundamental GPU architectures. They demonstrate the model's accuracy in capturing the intricate behaviors of GPUs through rigorous analysis and experimentation, both in terms of memory access patterns and thread execution dynamics.

Zhou et al. [18] acknowledge the growing trend toward billion-scale machine learning models, which present significant challenges due to their massive memory requirements. MPress takes a novel approach to training by focusing on inter-operator parallelism and optimizing memory usage. MPress reduces the memory footprint by carefully orchestrating the data flow between operators in the neural network, making it possible to train large models on multi-GPU servers without excessive memory requirements.

It explains MPress's methodology in detail, emphasizing memory-saving techniques. These techniques include novel inter-operator parallelism strategies allowing more efficient use of available memory resources. MPress enables researchers and practitioners to train billion-scale models on conventional multi-GPU servers by reducing the memory overhead associated with these models democratizing access to large-scale machine learning capabilities.

Furthermore, the authors demonstrate MPress's effectiveness in the paper's experimental results. These experiments show significant memory savings and efficient multi-GPU scaling when training billion-scale models, validating the proposed framework's practical applicability and effectiveness.

Zhang et al. [19]. Introduced the significance of task parallelism in modern computing applications. They are particularly interested in dynamic task parallelism, in which the number and complexity of tasks can vary dynamically during program execution. Traditional parallel processing models face difficulties dynamically managing tasks and allocating computational resources efficiently.

The CPU-assisted GPU thread pool model proposed here introduces a strategic collaboration between CPUs and GPUs. It uses a thread pool mechanism to dynamically assign tasks to threads based on their complexity and computational requirements. The CPU is critical in orchestrating these tasks, distributing them efficiently among available GPU threads. The model ensures optimal utilization of CPU and GPU resources by intelligently managing task allocation and synchronization.

TABLE I. COMPARISON OF HETPIPE WITH GPIPE, PIPEDREAM, AND XPIPE

Features	**Model Parallelism Libraries**			
	GPipe	***PipeDream***	***HetPipe***	***XPipe***
Heterogeneous cluster support	No	No	Yes	Yes
Target large model training	Yes	No	Yes	Yes
Number of workers (virtual)	1	1	No	No
Data parallelism	Extensible	Partition	Virtual Workers	Pipeline Model Parallelism
Proof of convergence	Analytical	Empirical	Analytical	Empirical

The study delves into the technical aspects of this hybrid computational model, revealing information about task scheduling algorithms and coordination mechanisms. The authors present experimental results that demonstrate the efficacy of their method. These experiments show improved performance in managing dynamic task parallelism, which makes the proposed model especially useful for applications with varying computational workloads.

Hong et al. [20] delved into the unique challenges posed by GPUs. It reflects on their previous work on developing an analytical model incorporating memory-level and thread-level parallelism awareness.

The authors revisit their earlier work in this study and provide a retrospective perspective on the analytical model they developed. The model was created to account for the complexities of GPU architectures by considering both memory-level parallelism (MLP) and thread-level parallelism (TLP). Memory-level parallelism refers to the execution of memory operations concurrently, whereas thread-level parallelism refers to executing multiple threads together.

The work discusses the motivations for developing the analytical model, emphasizing the importance of understanding the dynamic interactions between memory access patterns and thread execution behaviors in GPUs. The authors thoroughly explain the model's components and the methodologies used to incorporate memory and thread parallelism awareness. They also discuss how the model has influenced their understanding of GPU performance characteristics, such as memory bottlenecks and thread throughput limitations.

The work [21] emphasizes the difficulties of scaling deep learning models to multiple GPUs, emphasizing the importance of efficient inter-GPU communication and user-friendly training code adaptation. The training library must support such communication, with varying overhead depending on the methods used, which adds to the complications of multi-GPU training. Furthermore, users frequently face the burden of extensively modifying their training code to take advantage of inter-GPU communication. Existing TensorFlow library methods are criticized for their non-negligible communication overhead and the significant code changes required, discouraging many researchers from pursuing multi-GPU training. Horovod, an open-source library designed to address these challenges, is introduced in the paper. Horovod provides efficient inter-GPU communication by reducing ring size, reducing overhead, and requiring only a few lines of user code modification. This makes distributed training in TensorFlow faster and more accessible, addressing the challenges of scaling modern deep learning models.

III. DISCUSSION

In the framework of current machine learning applications, Tab. 2 summarizes the main ideas and contributions from each of the studies mentioned.

Delving into the extensive body of literature on parallel computing for deep learning reveals that the field has undergone a transformative phase marked by innovative strategies to improve the efficiency and scalability of machine learning algorithms. This research has investigated various parallel computing aspects, from traditional data parallelism to ground-breaking techniques such as pipeline parallelism, inter-operator parallelism, and memory-aware model parallelism. These methods effectively address the challenges posed by large-scale DNN models and serve as a steppingstone toward democratizing access to high-performance computing resources.

A key takeaway from this literature is the critical role of collaboration among experts from various domains. The

interdisciplinary nature of these studies, which entails the expertise of computer scientists, engineers, and domain-specific researchers, exemplifies the synergy that occurs when different perspectives collide. This collaborative effort resulted in practical solutions based on theoretical insights, highlighting the importance of a multidisciplinary approach in addressing complex challenges in artificial intelligence.

Furthermore, the literature emphasizes the critical importance of considering the real-world implications of these advances. While the studies show significant improvements in training efficiency and model accuracy, they highlight substantial challenges, particularly regarding integration complexities and ethical considerations. The seamless integration of parallel computing techniques into existing infrastructures necessitates careful planning and concern, particularly in industries that require real-time processing and precision, such as healthcare and finance.

Furthermore, the environmental impact of large-scale parallel computing cannot be ignored. The energy required to train models grows significantly as they become more complex. This reality necessitates a critical examination of eco-friendly practices and the development of energy-efficient computing solutions. Collaboration between researchers and industry experts is essential to developing green computing strategies, ensuring that adverse environmental impacts do not undermine the benefits of parallel computing.

Literature not only provides valuable insights into the democratization of artificial intelligence, but it also contextualizes it within practical applications. These studies have made it possible to train sophisticated models on standard hardware by optimizing parallel computing techniques, making advanced machine learning capabilities accessible to a broader audience. This democratization has far-reaching implications, particularly in fields such as healthcare, where AI-driven diagnostics and personalized treatments can transform patient care, and education, where intelligent tutoring systems can significantly improve learning experiences. This multifaceted impact highlights parallel computing's transformative power in shaping a more accessible and impactful future for artificial intelligence applications across multiple domains.

Model parallelism has demonstrated its effectiveness in improving training efficiency and model accuracy across a wide range of domains. Notably, in natural language processing, BERT has used model parallelism to distribute its massive parameters efficiently, achieving state-of-the-art results in tasks such as question answering and sentiment analysis. Similarly, Open AI's GPT-3 uses both data parallelism and model parallelism, distributing model segments across GPUs to achieve efficient training and the generation of contextually relevant text on various prompts. Model parallelism optimizes the training of deep Convolutional Neural Networks (CNNs) in computer vision, particularly for large-scale image classification tasks, demonstrating improved efficiency and scalability.

Model parallelism is implemented in distributed deep learning frameworks such as Horovod, reducing communication overhead and accelerating the training of large-scale models in tasks such as image and speech recognition. Furthermore, model parallelism effectively trains models representing complex policies in reinforcement learning, particularly in applications such as robotics. These examples demonstrate model parallelism's versatility and success in addressing challenges associated with large-scale deep-learning models, improving training efficiency and model accuracy.

Model parallelism integration in deep learning frameworks poses complex challenges requiring nuanced solutions. One major challenge is partitioning complex computational graphs across multiple devices, necessitating heuristic-based approaches and optimization algorithms for optimal distribution. Inter-device communication introduces latency and overhead, necessitating efficiency-enhancing strategies such as gradient compression and specialized communication libraries such as NCCL [22]. The issue of balancing synchronization in training, which is critical for maintaining model integrity, is addressed using hybrid approaches that combine synchronous and asynchronous methods. Adaptive techniques like model slicing and dynamic graph construction are required because of the dynamic nature of modern network architectures, such as recurrent neural networks and attention mechanisms. Specialized tools like TensorFlow’s distributed tracing and Horovod's built-in profiling capabilities debug and profile distributed model parallel systems. It is critical to ensure user-friendly APIs for widespread adoption, and frameworks such as PyTorch and TensorFlow are evolving to provide high-level abstractions, making model parallelism more accessible. In practice, the convergence of algorithmic advances, specialized libraries, and user-friendly tools contributes to the efficient integration of model parallelism, constantly refining the landscape of distributed training in deep learning frameworks.

TABLE II. KEY FINDINGS OF THE STUDY

Study	Key Findings
Goncharo et al. [8]	They addressed the need for multi-GPU training capabilities and effective CPU parallelization within the Ariadne library for deep learning.
Harlap et al. [9]	They introduced PipeDream, a pipeline parallel computing architecture, to reduce communication overhead and maximize GPU utilization.
Chen et al. [10]	They proposed a pipelined model parallelism strategy, including the "SpecTrain" weight prediction method, for enhanced DNN training efficiency.
Huang et al. [11]	They Developed GPipe, a pipeline parallelism library for effectively scaling DNN capacity across various machine-learning tasks.
Shoeybi et al. [12]	They Presented techniques for training large transformer models, showcasing substantial improvements in Natural Language Processing applications.
Park et al. [13]	They Introduced HetPipe, a novel DNN training method that combines data parallelism with pipelined model parallelism for heterogeneous GPU clusters.

Study	Key Findings
Ström [14]	Through an innovative weight update strategy, she addressed communication bottleneck issues in distributed stochastic gradient descent (SGD) training.
Guan et al. [15]	They Developed XPipe, an efficient and scalable pipeline model parallelism technique for training DNNs across multiple GPUs.
A. Jain et al. [16]	GEMS, a GPU-enabled memory-aware Model-Parallelism System, enhances large-scale distributed deep neural network training by managing memory usage, incorporating novel techniques, and leveraging GPU computational power.
Hong et al. [17]	They proposed an analytical model for understanding GPU architectures, considering memory- and thread-level parallelism dynamics.
Zhou et al. [18]	They Introduced MPress, a memory-efficient training approach emphasizing inter-operator parallelism for large-scale DNN models.
Zhang et al. [19]	They highlighted the significance of task parallelism, particularly dynamic task parallelism, and the collaboration between CPUs and GPUs.
Hong et al. [20]	Respond to the challenges posed by GPUs by revisiting their analytical model, emphasizing the importance of memory-level and thread-level parallelism awareness, and demonstrating its accurate prediction of GPU-based system behavior through validation against real-world implementations.
Sergeev et al. [21]	The article discusses the challenges of training deep learning models on multiple GPUs, introducing Horovod, an open-source library that simplifies distributed training in TensorFlow, enhancing model performance.

IV. Conclusion

The literature review emphasizes parallel computing techniques' transformative impact on deep learning and computational science. The transition from traditional data parallelism to novel methods such as pipeline parallelism, inter-operator parallelism, and memory-aware model parallelism represents a significant step forward in large-scale machine learning tasks. These methods improve DNN training efficiency and democratize access to complex models, allowing for exploration in areas such as natural language processing and scientific simulations. However, challenges remain, necessitating ongoing research to integrate these techniques seamlessly into existing infrastructures and address emerging ethical and environmental concerns related to large-scale computing. Collaboration, ethics, and sustainability are critical in realizing parallel computing's potential for societal improvement and human knowledge advancement.

Reviewing the extensive literature on model parallelism in GPU computing reveals significant research gaps. It is critical to optimize techniques for heterogeneous GPU architectures to use GPUs with varying capabilities efficiently. Scalability studies are critical for investigating the limits of model parallelism as deep learning models grow, as well as trade-offs between model size, GPU numbers, and communication overhead. Due to the lack of dynamic workload management strategies, adaptive model parallelism techniques that can distribute model layers based on varying computational requirements are required.

Model energy-efficient parallelism is essential, prompting research into techniques that optimize energy usage while maintaining accuracy. Protocols enabling seamless integration of model parallelism into popular deep learning frameworks are required to address standardization and compatibility issues across frameworks. There is a lack of empirical studies across a wide range of real-world applications, emphasizing the need for practical implementations to assess model parallelism's performance, challenges, and domain-specific enhancements. It is critical to close these gaps if model parallelism in GPU computing is to progress and become widely used.

Model parallelism is revolutionizing various aspects of medical applications in the healthcare sector. Model parallelism is used in medical imaging to improve the accuracy and efficiency of deep learning models, resulting in more precise diagnoses and treatment plans. The technology speeds up drug discovery processes by more accurately predicting molecular interactions, potentially leading to the development of new medications. Model parallelism is also used in disease prediction based on comprehensive patient data, genomics, and clinical records, promoting early interventions and personalized treatment strategies. Model parallelism causes transformative changes in education, particularly in personalized learning. Model parallelism-based adaptive learning models cater to individual student needs and learning styles, increasing engagement and academic performance. Natural language processing applications in education, such as automated grading and language tutoring, are powered by technology, providing students with timely and personalized feedback. Furthermore, model parallelism in educational research facilitates the training of sophisticated models to understand learning behaviors and predict student outcomes, enabling evidence-based strategies for improved learning experiences. These applications highlight the tangible benefits of model parallelism in healthcare and education, providing unprecedented accuracy, efficiency, and personalization advances.

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2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

Short-Term Road Traffic Forecast using LSTM-based Deep Learning Model

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***Abstract*—Real-time traffic predictions have now become a time-being need for efficient traffic management due to the exponentially increasing traffic congestion. This paper introduces a pragmatic traffic management system, especially for countries such as Sri Lanka where proper traffic database is absent. This system involves TFmini Plus light detection and ranging light detection and ranging (LiDAR) sensor for real-time traffic monitoring and vehicle count for next five minutes will be predicted by feeding consecutively collected data into the LSTM neural network. The sensor attains 89.7% accuracy, even in irregular traffic patterns in Sri Lanka. In the model training process, with a constant input data volume of 8,064 points, varying the window size to 6, 12, 24, 60, and 288 showed an improvement in prediction accuracy for 6, 12, and 24 window sizes, while it was declined for 60 and 288. The peak accuracy occurred with a window size of 24. Altering the input data volume from 2,016 to 8,064 points while keeping the window size at 24 resulted in a consistent accuracy increase with larger data volumes. 75.34% accuracy was experiments demonstrate that the proposed method for traffic flow prediction has superior performance. Moreover, accuracy results ensure that this system is capable to address Sri Lankan traffic conditions.**

Keywords—Real-time traffic monitoring, LSTM neural network, traffic predictions, LiDAR sensor traffic monitoring

I. INTRODUCTION

Road traffic has intensively escalated in recent years, causing widespread congestion, and emerging as a prominent issue. According to Victoria Transport Policy Institute's Congestion Costing Critique (CCC), published in 2021 [1], congestion cost is estimated to cost between $130 to $500 per capita annually, particularly compared to $2,000 in crash damages. Similarly, it estimates that by 2025, congestion cost will have risen to $200 billion [1]. According to the National Highway Traffic Safety Administration's statistics (NHTSA) [2], more than 2.3 million injuries and 32,719 deaths were recorded due to vehicular accidents, with traffic congestion identified as a major contributor [2, 3]. Additionally, congestion led to 5.5 billion lost hours, 2.9 billion gallons of fuel wasted, and approximately 31% of CO2 emissions (56 billion pounds) annually [2, 4]. INRIX's 2021 indicates that global traffic strategies, including intelligent systems with adequate traffic sensing infrastructure, are effective but predominantly limited to developed countries [5].

This absence hinders effective traffic management, making it challenging to assess the progress of mitigation projects. In the inherently random nature of traffic, robust data and strategic sensor placement are vital for effective and intelligent traffic management systems (ITMS) [6].

The paper proceeds as follows: below Section II outlines the research problem in the context of Sri Lanka. Section III delves into the literature of real-time traffic monitoring and forecasting, addressing research gaps. Further, parts A and B of Section III provide an extensive evaluation of each method, including tables comparing their performances. Section IV expresses the methodology, while Section V presents results and validation. Section VI concludes by summarizing findings and introducing future work.

II. RESEARCH PROBLEM DEFINITION IN THE CONTEXT OF SRI LANKA

Traffic congestion is a major issue in Sri Lanka [7]. Excessive fuel consumption due to prolonged travel time results in economic loss and frequent accelerations, leading to frequent repairs creating a significant loss to the national economy [8]. The congestion cost in Sri Lanka's western province exceeds Rs. 20,000 million per year, approximately 2% of regional GDP [9]. Moreover, Sri Lankan transport sector is responsible for 25% of greenhouse gas (GHG) and 47% of CO2 emissions, compared to global averages [10]. Sri Lankan government initiatives to alleviate traffic jams in Sri Lanka include short-term measures such as building new transport infrastructures, roads, expressways, and expanding existing capacities [11]. In addition, long-term strategies involve revising vehicle ownership and public transport policies to align with road and transport capacities [9]. However, none of the above measures have been able to create a significantly effective impact on traffic management than implementing an ITMS. Therefore, the absence of an implemented ITMS in Sri Lanka appears to be the cause of the existing congestion.

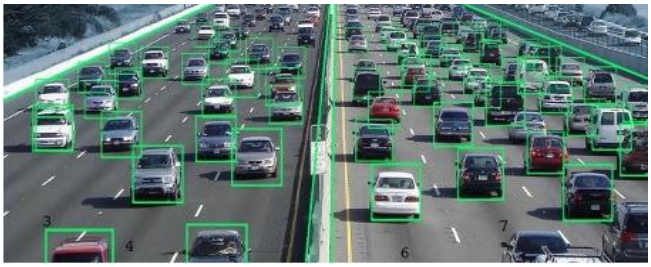

Fig. 1. Systematic traffic behaviour of other countries

Fig. 2. Traffic Behaviour of Sri Lanka

In contrast to countries with well-disciplined drivers, Sri Lankan vehicles often follow lack systematic lane adherence and adequate spacing. Fig. 1 and 2 depict Sri Lanka's traffic behavior compared to countries like Russia, Australia, and Europe. Fig. 1 shows vehicles maintaining proper spacing and moving in a single lane, while Fig. 2 illustrates Sri Lanka's traffic with vehicles closely positioned and disregarding lanes. This irregular behavior poses a significant challenge, impeding the effectiveness of image processing-based traffic monitoring systems. The unpredictable nature of traffic in Sri Lanka complicates the generation of accurate contours, particularly affecting vehicle identification.

Even though the color lights are there for alleviate congestion, their lack of intelligence and fixed programming is a hindrance. This often results in instances where the green light persists even in the absence of vehicles, causing traffic jams and restricting access for vehicles in other lanes [12]. Additionally, poor technical and digital literacy poses another obstacle. Even though many traffic surveys are conducted annually, there is a lack of a proper traffic database, and no automated system exists to retrieve past data for analysis to perform estimations, comparisons, or traffic predictions [13].

Nowadays Sri Lankan government is grappling with a large fiscal deficit, with the depreciation of the Sri Lankan rupee against major currencies and high debt. Since traffic congestion is a major factor affecting the country's economy, this real-time traffic management system has been developed to seamlessly align with the existing road conditions and technical constraints in Sri Lanka.

III. Literature Review

As early as the 1970s, an autoregressive integrated moving average (ARIMA) model for short-term highway traffic flow forecasting was introduced which has been recorded as the foremost approach under ITMS strategies [14]. Since then, a wide range of traffic forecasting models have been proposed along with traffic surveys to address this traffic issue with better traffic management. Hong Kong's road network, which is one of the busiest roads in the world, underwent a substantial improvement in traffic management through the implementation of an ITMS, effectively tracking its all major highways, roads, and tunnels [15].A low-cost sensor-based traffic monitoring network instrument was developed and tested to be used in a work zone [16]. Al-Holou et al. [17] developed a multi-dimensional model to estimate the influence of vehicles on the environment, traffic congestion, and traffic safety.

A. Traffic Detection Methods

Vehicle detection and surveillance play an integral role in both effective traffic management and ITMS. Since ITMS plays a critical role in national traffic management systems (TMS), the quality of provided data and the geographical arrangement of traffic sensors are also important factors for ITMS success [6].

Common vehicle detection technologies can be classified into three groups: intrusive, non-intrusive, and off- roadway sensors [18]. The inductive loops, magnetic detectors, piezoelectric sensors, weight-in-motion sensors and pneumatic road tubes are considered as invasive sensors. These are usually embedded in the road surface after saw-cutting the surface or adding roadway holes. The detection methods such as vision- based systems such as image processing traffic monitoring systems, infrared sensors, microwave radar and ultrasonic detectors are non-intrusive sensors which can be installed atop roadway or roadside surfaces or mounted overhead [18]. Remote sensing through airplanes or satellites and probe vehicles with GPS receivers are examples of off-roadway sensors [19], [20]. Consequently, these sensors are not suitable for large-scale integration, which are stationed in strategic areas and operate independently.

Video Image Processor is a very common traffic monitoring method since now Image processing has become a tendency and the most prominent traffic monitoring system in the world [6]. Video Image Processor (VIP) systems normally consist of a camera, a processor-based workstation for analyzing the images, and transforming them into data [6, 21]. Image processing systems provide live images of real-time traffic status, which covers multiple detection zones. So that it offers broad area detection [22]. In VIP systems, vehicular detection is performed using the contours drawn in the snapshots taken in constant time intervals [23]. It also offers occupancy, classification, and count of vehicles, as usual in most other sensors. Moreover, in the literature, several disadvantages of image processing have also been discussed. Being sensitive to weather conditions, vehicle shadows, and dust on the camera lens is notable. Additionally, camera mounting requirements such as height for better measurements, higher installation and maintenance costs are also significant drawbacks of these camera-based systems [22]. It also requires costly equipment for real-time video-image and data transfer, separate algorithms for day and night traffic detections [22].

Light Detection and Ranging (LiDAR) technology is a novel technology in which research and investigations have been performed in recent years [24, 25]. LiDAR is a remote sensing method that uses light in the form of a pulsed laser to measure ranges of variable distances. The point cloud of LiDAR data is made up of thousands of points in X, Y, and Z coordinates [25]. Downsampling, noise reduction, object grouping, distant irrelevant object rejection, and ultimately vehicle recognition utilizing point cloud data are all part of this architecture [26, 27]. Geometric characteristics such as size, form, and height are retrieved for categorization in this method. Besides, there are a variety of other traffic monitoring technologies embedded with various electronic sensors. The strengths and weaknesses of each traffic monitoring technique are compared in Tab. 1 below.

TABLE I. COMPARISON OF TRAFFIC MONITORING TECHNIQUES

Type of the detector	Detector Methods Comparison		
	Working Mechanism	***Strengths***	***Weaknesses***
Inductive loop [28]	Detects vehicles by sensing the loop	• Flexible design to fullfil a great variety of applications. • Unresponsive to bad weather. • Offers accurate count data.	• Traffic disruptions may occur during installation and maintenance • Prone to damage by heavy vehicular movements
Microwav e radar [28]	Transmits signals in recognition regions and captures the echoed signals	• Unresponsive to bad weather. • Speed is measured directly. • Multiple lane operation.	• Incapable of sensing immobile vehicles in outdoor applications
Acoustic [28]	Detect audible sounds produced by vehicular traffic. Using them vehicle presence and speed are measured[29]	• Applicable where loops are not likely. • Insensitive to bad weather. • Installation of some models does not require a pavement cut. • Less error prone than inductive loops.	• Installation needs a boring under the road. • Incapable of sensing immobile vehicle
Ultrasonic [28]	Sends ultrasonic waves to an object and captures the returning echoes.	• Monitors multiple lanes. • Proficient in detecting over-height vehicles.	• Environmental circumstances may affect. • Occupancy measurement may degrade with large pulse repetition periods.
VIP (Video image processor) [28]	This system normally consists of a camera, processor, and software	• Monitors multiple lanes. • Simple to add and change detection areas. • Offers broad-area detection	• Performance is sensitive to bad weather, vehicle shadows, and dust on the camera lens. • Requires specific camera mounting height for finest vehicle presence detection.
Light Detection and Ranging (LIDAR) [28]	This is a remote sensing method that uses a pulsed laser to measure ranges of variable distances	• Monitors multiple lanes. • Simple to add and change detection areas. • Insensitive to bad weather. • Offers broad-area detection	• Traffic disruptions while installation and maintenance.

B. Prediction Methods

Traffic flow is a real-time, totally non-linear, and high-dimensional random process [30]. Reviewing the literature emphasizes that vehicle forecasting is a common research topic [31, 32]. According to the reference [32], traffic forecasting is classified into two basic categories: long-term prediction and short-term prediction. The projection for the near future, spanning the next 5 to 10 minutes, is called short-term prediction, anticipating immediate changes due to factors like weather, events, or accidents [32].

There are comparative research articles which evaluate accuracy and efficiency of the prediction models. Among them [31, 32] and [33] references emphasize that both data-driven and experimental traffic flow prediction approaches can be classified as parametric, non-parametric, and hybrid, each having its own set of benefits and drawbacks. Linear regression, maximum likelihood (ML), Historical Mean Average, and exponential smoothing method are some of the parametric prediction approaches [32]. Parametric prediction methods are more accurate than the other two methods, yet its poor functionality amid the noise and other disturbances is an encountered major drawback [32, 33].

1) Non-Parametric Models: The number of parameters which assigned to a model is flexible. Therefore, the model structure and parameters are developed based on available data. These models have the benefit of allowing for the discovery of intricate non-linear correlations between traffic factors. In contrast, unanticipated events and outliers may effect when the model's structure is derived from the data [33]. The intricacy and their reliance on vast amounts of data are the other drawbacks. Neural networks, such as the multilayer perceptron (MLP), time-delay neural network (TDNN), and radial basis function (RBF) are the most popular and prominent non-parametric approaches. Besides these neural networks, Fuzzy [34], Bayesian networks k-nearest neighbor (KNN) [35], support vector machine, and wavelet are other non-parametric methods used for predictions [32].

Neural network is the most common traffic prediction method with its ability to model and simulate complicated non-linear relationships [33], [36]. There are different neural network types such as Feedforward neural networks, Convolutional Neural Network (CNN), Recurrent neural networks (RNN) and Long Short-Term Memory networks (LSTM) based on their training procedure, internal structure, methods of pre-processing input data and their models including spatial or temporal patterns [37]. Among them, LSTM is the most powerful model for sequential data [38]. The type of the neural network varies depending upon the application. As per mentioned in the research paper by Van Hinsbergen, Van Lint, et al., a typical neural network might deliver reliable findings in terms of extensions required for higher accuracy in traffic predictions [33].

2) Parametic Models: The model's structure and the number of parameters are fixed, and the model's parameters must be derived using data. These models excel in capturing unseen cases, requiring less data and sometimes offering higher accuracy with less computational work [33]. Hybrid models combine parametric and non-parametric prediction models, achieving higher prediction accuracy. Many hybrid models are combinations of neural networks and other parametric and non-parametric models such as ARIMA, MLP, and fuzzy. According to the reference [32], neural network-based MLP models are the most suitable prediction models for data-driven traffic forecasting systems with image processing compared to all other models.

Despite the facts that were included in literature review on these parametric, non-parametric and hybrid prediction models and the projects and research approaches evaluate the existing gaps subject to traffic predictions, there can be seen an outstanding tendency toward using Long Short-term Memory (LSTM) neural networks for traffic predictions, especially in recently published research articles. The reference [39] evaluates the growing adoption of LSTM

algorithms for traffic prediction, highlighting their increasing prevalence. Another research carried out on LSTM [30], indicates that most prediction methods prioritize accuracy over immediacy.

LSTM neural networks, an advancement over RNNs, effectively tackle the vanishing gradient problem and long-term dependency issues [40, 41]. However, the reference [42] claims that even though most of the novel traffic management approaches used LSTM models, those existing projects and their models have failed to address the issue of massive traffic flow data being processed simultaneously with parallel to computing and distributed data storage [43], [44]. But it also emphasizes that the LSTM model is a better prediction model for more random and time-varying predictions such as traffic flow [45]. Also, there are few studies focusing on the time series for the Internet of Things (IoT) traffic forecast [46, 47]. Tab. 2 compares the strengths and weaknesses of each prediction model.

TABLE II. PREDICTION MODELS COMPARISON

Prediction Model	**Prediction Models Comparison**	
	Strengths	***Weaknesses***
Mean Average model[48]	• Low Prediction Error.	• Poor functionality in the presence of noise. • Average of all inputs are needed for the predictions. • Higher reliance on data.
Linear Regression method[48]	• Low Prediction Error. • Predicts the next variable online using real data	• Poor functionality amid the noise and other disturbances
Maximum Likelihood (ML)	• Low Prediction Error. • Robust for sensor failures and rapidly changing conditions.	• High dependency on recorded data.
Exponential Smoothing Method	• Low Prediction Error.	• Poor functionality amid the noise and other disturbances. • Difficulties to determine constant coverage.
ARIMA Model	• Low Prediction Error. • Simplicity. • More mathematical model Obtain the relationship between past and future data.	• Poor functionality amid the noise and other disturbances. • High dependency on recorded data.
MLP Model	• High Accuracy. • Predict traffic flow in proportion to road conditions.	• High dependency on recorded data.
Fuzzy Model	• Low Prediction Error. • Simplicity. • High Accuracy.	• Poor functionality • High dependency on recorded data.
KNN Model[46], [48]	• High Accuracy. • Predict traffic flow in proportionto road conditions.	• Poor functionality amid the noise and other disturbances. • High dependency on recorded data.
Bayesian Networks	• High Accuracy. • Relatively Low Errors	• High dependency on recorded data.
LSTM NN [46], [49]	• High Accuracy. • Better for time-based models. • Relatively Low Errors	• High dependency on recorded data.

IV. METHODOLOGY

The methodology is introduced by being split into two main sections: the traffic monitoring stage and the forecasting stage using neural networks emphasizing the main milestones of the project.

A. Traffic Monitoring Stage

Vehicle detection was achieved by installing a TFMini Plus LiDAR sensor beside the road to monitor vehicles on one side, as per illustrated in Fig. 4. TFMini Plus sensor's Time of Flight (ToF) principle is used to detect the presence of vehicles [50]. Sensor's periodically emitted modulation waves are used to detect and calculate the proximity to the object and its time-of-flight is estimated by measuring the round-trip phase difference of its reflection when it contacts an object [51]. These waves are directed towards the road and emitted at a frequency of 16.667 Hz with content intervals. Sensor's distance limitations are set between 800 to 1220 meters, considering white lines that separate traffic in the same direction, ensuring the sensor is triggered only by vehicles moving in the intended direction, and not by pedestrian movements or vehicles traveling in the opposite direction. Additionally, distance measurement must persist longer than 50 milliseconds and return back to the initial value to count it as a vehicle (refer Fig. 3). And total vehicle count after every 5 minutes intervals delivered to an IoT database. ESP8266 microcontroller was used enabling further improvements with IoT connecting several nodes.

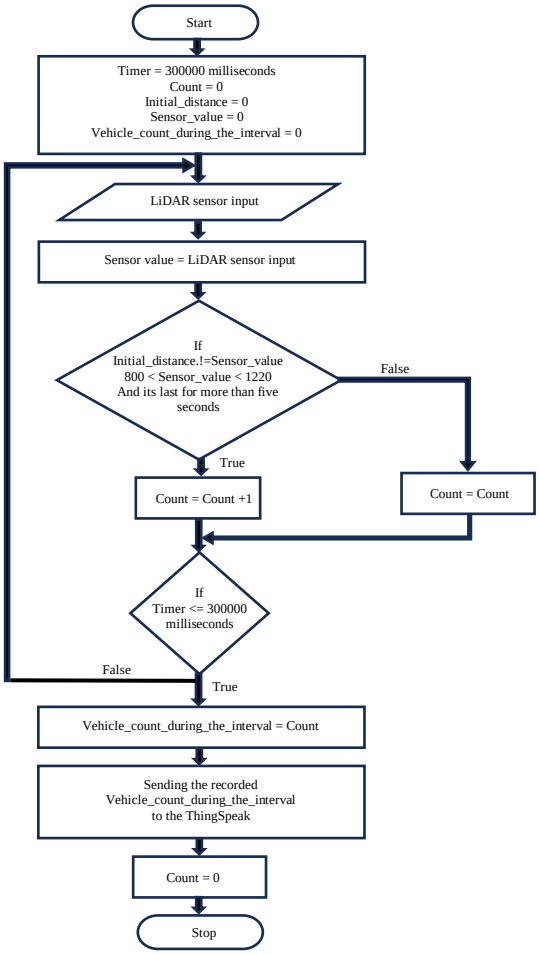

Fig. 3. Flow chart of the vehicle detection algorithm

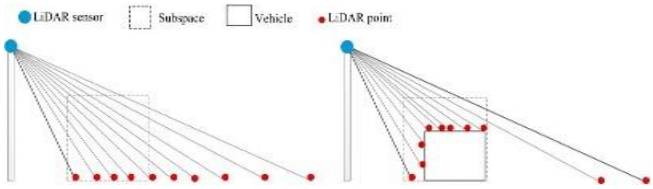

Fig. 4. An illustration of a subspace without (left) or with (right) a vehicle

B. Neural Network Training and Forecasting Stage

This stage involves training the LSTM neural network model, which includes data preparation and segmentation before initiating the training process. The data collected on ThingSpeak was exported as .csv files for LSTM model training. These modified .csv files were then input into the system in four segments, allowing for variations in the input data volume and window size to identify the optimal configuration for the prediction model.

Since the vehicle count is taken in five minutes intervals,

In one hour: 12 data points

In one day: 12 × 24 = 288 data points

In a week: 12 × 24 × 7 = 2016 data points

In a month: 12 × 24 × 30 = 8640 data points

Data collected over a five-week period, monitoring vehicular traffic, was utilized to build this forecasting models. This entire data collection was divided into two sets: a training set and a testing set. The training dataset consisted of 8,064 data points, collected over a month, while the remaining 2,016 data points, gathered over a week, served as the test dataset for model testing. The entire training dataset was further divided into four segments representing weeks 1, 2, 3, and 4 and the data patterns over a day and month were observed to identify the traffic behavior patterns. Subsequently, ten distinct models were trained to determine the most effective and accurate model.

Initially, the first set of models was created with a window size of 12, varying the input data volume from 2,016 data points to 8,064 data points. In the second model set, based on the results of the first four models, the input data volume was fixed at 8,064 data points, while the window size was varied to 6, 12, 24, 60, and 288. Here window size 6 means 6 data points (data gathered over 30-minute intervals) is fed to the system at a time. Likewise, four other models were trained for 1, 2, 5 and 24-hours data. Based on the results of those five models, the optimal window size was determined as 24. The third model set was trained setting window size to 24, while ranging the input data volume from 2,016 data points to 8,064 data points.

Then these trained model sets were critically assessed for accuracy to determine the most suitable prediction method. All accuracy-related computations in this project, including sensor accuracy and prediction model accuracy, were performed using the following two equations adhering IEEE standards [51]. Below (1) used to determine the error rate.

$$Error\ Rate = \frac{|\text{Observed Value} - \text{Actual Value}|}{\text{Actual Value}} \times 100\% \quad (1)$$

Once the error rate is calculated, accuracy was determined using below (2).

$$Accuracy = 100\% - Error\ Rate \quad (2)$$

V. Results and Validarion

A. Results of the Sensor Accuracy Test

First of all, the sensor accuracy was tested considering the data gathered during a random day. Taking actual vehicle counts from counting, and the sensor-detected vehicle counts from sensor records, actual vehicle count vs sensor-detected vehicle count plot was created. The accuracy of the sensor has been tested considering 200 data points which resulted = 89.86% accuracy. Fig. 5 illustrates the actual vehicle count vs sensor-detected vehicle count, highlighting that sensor detected vehicle count is almost closer actual vehicle count. This sensor accuracy plot also provides insights into the daily traffic behavior from 0:00 hours to 23:59 hours. It indicates that the traffic behavior during the day exhibits a normal distribution pattern, with higher values concentrated in the middle of the range, and a symmetrical tapering off towards both extremes.

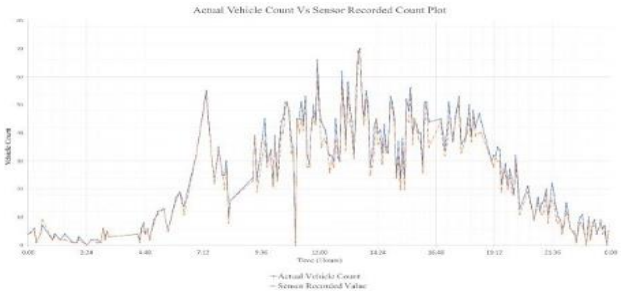

Fig. 5. Actual vehicle count vs sensor-recorded vehicle count

B. Traffic Behavior Analysis

After observing the traffic behavior of a day, the traffic behavior of over a week was also plotted. In this case, each day's traffic behavior exhibited a normal distribution pattern. Weekly traffic behavior appeared as a combination of seven normal distributions. Additionally, the traffic behavior of each week was also plotted to identify whether the traffic flow remains the same following a pattern every week or shows significant fluctuations. Below Fig. 6 represents the overall traffic behavior of the entire month. These plots were the only source to identify the traffic patterns and to decide the window size to train the model.

C. Prediction Results

There can be seen significant deviations in traffic flow after intervals of 60 minutes (during an hour). Therefore, first it was identified it is better to take 12 data points at a time to train the prediction model. Then the desired window size was kept to 12 and using data gathered over a month the very first LSTM neural network model was trained. Below Fig. 7 illustrates the resulted predicted traffic behavior vs test data plot and Fig. 8 illustrates the entire plot of the trained data, test data and resulted predicted traffic data. Finding the best traffic prediction model is one major research objective of this project. Therefore, more than ten LSTM neural network models were created and evaluated in terms of accuracy to identify the most suitable forecasting model. Here all the result accuracies were more than 70%. And no model exhibits large deviations in predicted traffic behavior vs test data plot.

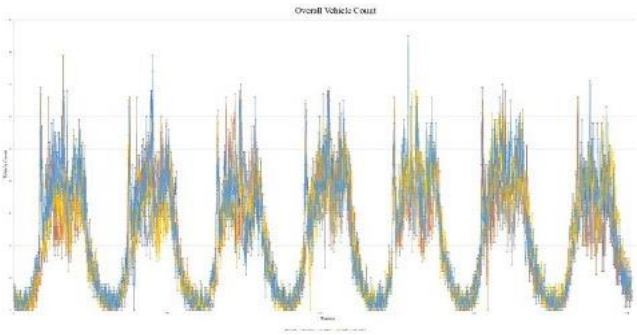

Fig. 6. Overall traffic behavior of each week

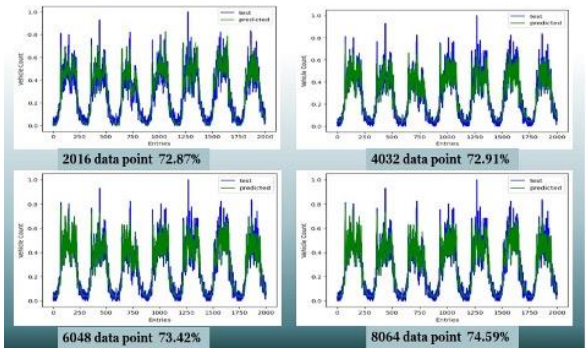

Fig. 7. Predicted traffic behavior vs test data plots

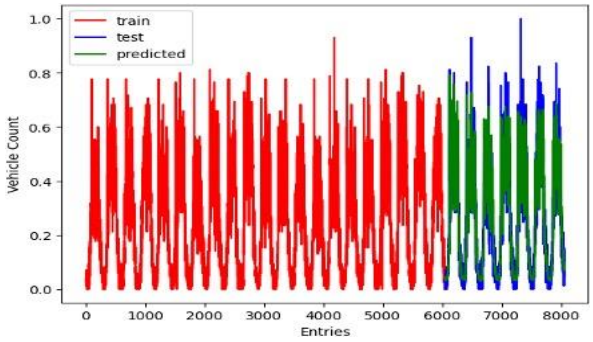

Fig. 8. Predictions results of the most precise forecasting model

TABLE III. ACCURACY TABLE OF MODEL SET_1

Volume of Input (Data Points)	*Window Size*	*Accuracy %*
2016	12	72.87
4032	12	72.91
6048	12	73.42
8064	12	74.59

TABLE IV. ACCURACY TABLE OF MODEL SET_2

Volume of Input (Data Points)	*Window Size (Data Points)*	*Accuracy %*
8064	6	74.49
8064	12	74.59
8064	24	75.34
8064	60	73.58
8064	288	72.07

TABLE V. ACCURACY TABLE OF MODEL SET_3

Volume of Input (Data Points)	*Window Size*	*Accuracy %*
2016	24	74.20
4032	24	73.78
6048	24	73.96
8064	24	75.34

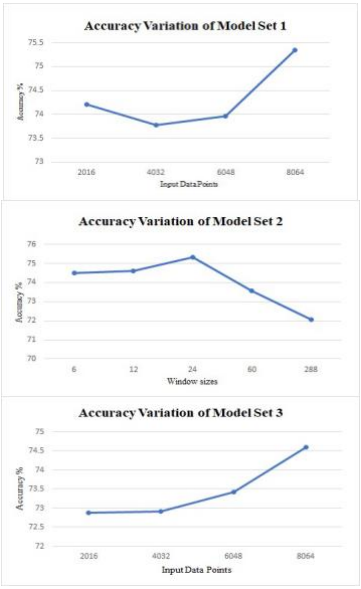

Fig. 9. Accuracy variations of the prediction model sets

Further, the prediction accuracy results of these test models which are presented above shown in Tab. III, IV, and Tab. V emphasize that both window size and the volume of the input data creates a significant impact on the prediction accuracy of the prediction models. The accuracy test results of all the 3 model sets show that all of them were above 70%. Above Tab. 3 represents the training model set 1 created by setting the window size to 12 while changing the input data volume from 2016 data points to 8064 data points. In model set 1, a noticeable improvement in accuracy was observed as the input data volume increased. In the second model set (as shown in Tab. 4), the input data volume was kept constant at 8,064 data points, while the window size was varied to 6, 12, 24, 60, and 288. Although the accuracy improved in the first three models, a noticeable decline in accuracy was observed with larger window sizes. This suggests that the most appropriate window size is 24. In the third model set, presented in Tab. 5, the window size was set to 24, and the input data volume was again adjusted, ranging from 2,016 data points to 8,064 data points. There also can be seen a consistent increase in accuracy with larger input data volumes. Fig. 9 displays multiple plots comparing predicted traffic behavior to test data. These plots are remarkably similar, with closely aligned predicted and actual traffic behaviors. Fig. 10 provides a graphical representation of the data from Tab. 3, 4, and 5. It offers a visual comparison of the accuracy results obtained from each model set. Meanwhile, it indicates that increasing the input data volume leads to a gradual improvement in accuracy. However, it also implies that the window size should be kept within a certain range, as excessive increases in the window size can lead to reduced accuracy beyond a certain point.

Based on the results, the best prediction accuracy is achieved with a 24-window size for training, in which the data gathered for two hours will be fed into the system at a time and increasing the input data volume to the greatest extent possible. Similarly, resulted accuracies indicate that highest precision can be achieved when the model is trained using 80% data and tested using 20% data.

VI. Conclusion

Results from sensor accuracy tests and prediction models emphasize the successful achievement of the main objectives and the effective contributions of utilized strategies in reducing traffic congestion, particularly in Sri Lanka. Furthermore, several benefits are evident in this project. The cost-effectiveness, easy implementation, and adaptability to various traffic behaviors stand out as notable advantages of this system, surpassing other ITMS in the literature.

Monitoring vehicular movement in Sri Lanka, is challenging with its erratic traffic patterns. However, this traffic monitoring method, using TFmini plus LiDAR sensor, provides accurate readings, achieving 89.86% accuracy even under the that unsystematic traffic conditions. Hence, the sensor proves its adaptability to diverse traffic environments, addressing Sri Lanka's traffic issues effectively. Unlike video-based systems requiring advanced technology and significant capital, this system is more suitable for Sri Lanka's technical capabilities and traffic infrastructure due to its affordability and compatibility. Its resistance to dust and rain also makes it well-suited for placement in such environments. Many traffic forecasting models rely on extensive traffic databases to train their prediction models. Image processing models also require prior data to identify vehicles. However, in Sri Lanka, traffic database collected over extended period unavailable. Therefore, the prediction model introduced in this project is better suited for countries like Sri Lanka as it doesn't necessitate a large dataset for training. The achieved prediction accuracy results indicate that this model can deliver predictions with 74.20% accuracy even it is trained using data gathered over just one week. Thus, the absence of a substantial traffic database no longer poses a hurdle to implementing traffic prediction models with this system.

However, the biggest challenge is the sensor needs to run 24x7. The loss of a few hours of data can substantially affect predictions. Maintaining a high level of reliability, preferably close to 100%, becomes imperative. Despite the increased difficulty, ensuring the consistent performance of the sensor is a necessary and critical aspect. Besides that, the road infrastructure in Sri Lanka differs from many other countries. Unlike the typical one-directional roads in most nations, Sri Lankan roads often accommodate vehicles moving in both directions, demarcated by white lines in the middle. Since here the sensor is situated on one side of the road, to track vehicles in one direction, sometimes there may be unavoidable miscounting of vehicles if a vehicle overtakes another vehicle by crossing the lane. Similarly, most of the vehicles in Sri Lanka do not move adhering strictly to lanes which may occasionally impact the accuracy of sensor readings. Therefore, this system is a more practical approach for addressing traffic congestion, particularly in Sri Lanka, where the traffic behavior databases are scarce, and the traffic behaviour is messy and complex. Moreover, resulted prediction accuracy values demonstrate that increasing input data volume substantially enhances prediction model accuracy. Thus, this system can be initiated with a short one-month data collection period at the initial stage, with potential for further development and improved forecasting accuracy through continuous training data integration. Additionally, the system could incorporate mechanisms to prevent miscounting of vehicles when overtaking vehicles.

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2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

Supervised Learning Based Approach for UAV Localization in Indoor Environments

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***Abstract*— In the modern era, various real-time applications in indoor environments use Unmanned Aerial Vehicles (UAVs) for their internal operations. Day by day, the usage of UAVs in indoor spaces is gradually increasing. Using UAVs in indoor environments offers numerous benefits, including enhanced surveillance, monitoring, and data collection capabilities. The growing trend of incorporating unmanned aerial vehicles (UAVs) into interior environments underscores their potential to improve operational efficiency and safety across a wide range of sectors. When indoor GPS is unavailable, UAV localization tends to rely on vision-based techniques coupled with mechanical sensing, such as a visual navigation system or simultaneous localization. This research presents a machine learning-based supervised learning approach for indoor UAV localization using LoRa technology. This approach can serve as an additional solution for situations where GPS cannot function in indoor spaces.**

Keywords*—*Unmanned aerial vehicle (UAV), mini-UAV, indoor localization, machine learning (ML), ML for signal processing

I. INTRODUCTION

Unmanned aerial vehicles (UAVs) are the latest technological innovations that can be used for various assignments. UAV applications are confined to the outdoors and indoor environments; hospitals, greenhouses, industrial firms, nuclear power plants, hangars, shopping malls, warehouses, assembly lines, and so on are just a few examples of inside manufacturing and service sites where UAVs could be useful. In hazardous conditions, UAVs with image devices and sensors may conduct visual and sensory inspection functions [1]. UAVs can be found in a broad range of forms and sizes. Sizes range from many meters to a few centimeters. Academics are particularly attracted to mini-UAVs due to their small size, high agility, and low cost.

We often receive inquiries about the limitations of GPS availability indoors when discussing position monitoring. GPS technology has rapidly gained popularity for outdoor location applications. However, in indoor environments, GPS tracking is difficult to establish a reliable signal and maintain accuracy. There are two main reasons why GPS is ineffective indoors: weak signal strength and subpar performance. Indoor spaces, particularly buildings, can obstruct GPS signals, resulting in a significant weakening of the signal strength and a decrease in tracking accuracy. As a result, GPS tracking indoors becomes unreliable. Additionally, GPS technology itself has inherent limitations in terms of precision. While certain industrial applications require accuracy within half-meter ranges, GPS can only deliver such precision outdoors, typically within 5 to 10 meters. Due to these limitations, alternative positioning technologies have emerged for accurate indoor tracking and monitoring. These technologies include Wi-Fi positioning, Bluetooth beacons, and indoor positioning systems, which leverage local infrastructure or wireless signals within buildings to determine device location. Considering these factors when seeking indoor positioning solutions is important, as relying solely on GPS may not yield accurate results within indoor environments [2].

GPS is ineffective indoors due to the variety of conditions. Therefore, alternative indoor navigation algorithms for UAVs should be investigated. WiFi and Bluetooth have commonly used low-range signals in existing indoor and outdoor positioning systems. However, LoRa (Long Range) technology comes into play for applications requiring longer-range capabilities. LoRa offers an extended communication range, making it suitable for various scenarios. Whether indoors or outdoors, LoRa-based systems can deliver reliable and effective performance.

LoRa is a versatile technology that may be used for both indoor and outdoor applications. It provides exceptional precision while keeping a large communication range. LoRa can give accuracy within a range of up to five kilometers in metropolitan areas, allowing for dependable locating and tracking. The range extends considerably further in rural regions, reaching up to 15 kilometers. LoRa's long range makes it a perfect solution for various circumstances, providing for reliable and accurate location in various conditions. In this research, we used LoRa technology to predict the position of UAVs with machine learning techniques in the indoor environment.

This paper aligns a project on the Supervised Learning Approach for UAV Localization in Indoor Environments. While machine learning indoor localization has been extensively researched for slow-moving objects such as humans, a notable gap exists in studies focusing on ML-based indoor localization for fast-moving objects like UAVs. This presents various challenges, including signal fluctuations and diverse multipath types, particularly in environments where UAVs are in motion. Localization in three dimensions is a major focus of this project. It consists of three fixed LoRa reference nodes, each located in three different places inside a building in a triangular position, and one moving LoRa node mounted on the UAV and moves with it. Following Fig. 01 is

a diagram illustrating the basic concept of three-dimensional localization. As a result of their position, Reference Node 01, Reference Node 02, and Reference Node 03 can receive the RF signal emitted by the target node, enabling precise measurements and data analysis.

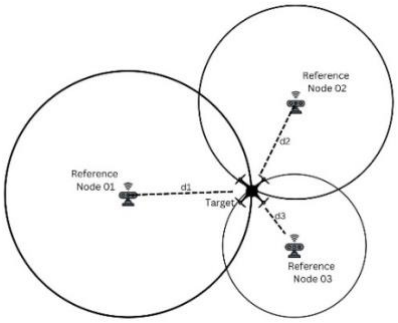

Fig. 1. Localization in indoor environments

This paper has been organized as follows. Section I gives the introduction, section II gives the Related Works, section III gives the Experimental Testbed and Dataset, section IV gives Model Training, section V gives Results and Discussion, section VI gives Future Works, and Section VII gives Conclusions.

II. Related Works

When discussing existing systems, we can learn about numerous approaches used for indoor positioning systems.

The paper [4], showcases a 3D laser radar-based UAV indoor detecting system. To estimate the UAV's velocity, they first receive the point cloud data from the UAV aerial lidar, extract its edge feature points and plane feature points, and then match the point cloud data from two successive periods. A point cloud map is being made in the meanwhile. Finally, the UAV scenario is tested using the public data set. In [5], it also presents a method with radar frequencies.

The method called Manifold Alignment with Mobile AP Detection is used in [6], and in this case, the mobile WLAN APs reduce positioning accuracy. In some research, they have presented methods with Magnetic Field Measurements for Indoor Positioning. [7] is a related research for that method, and Readings of the magnetic field are the major source of information needed to identify where the platform is. The paper [8] presents a visual-inertial odontography localization technique based on fiducial markers. That technology enables multi-rotor aerial vehicles to navigate in interior environments and handles the most challenging aspects of image-based indoor localization. The emphasis of the study in [9] is on indoor UAV localization using an Inertial Measurement Unit (IMU). They use data from onboard sensors such as accelerometers and gyroscopes to determine the UAV's position and orientation within its internal environment.

The objective of the research in [10] is to look at UAV indoor localization utilizing Bluetooth Low Energy (BLE) beacons. They deploy Bluetooth low-energy beacons around the facility and use signal strength or proximity information to predict the location of the UAV using appropriate algorithms. In the study [11] they looked at the viability of employing UWB signals to place UAVs in interior settings precisely, and they suggested a localization technique based on time-of-flight measurements. The paper [12] analyzes magnetic field patterns in the inside environment and creates algorithms to predict the UAV's position based on these patterns.

Research [13] investigates indoor UAV localization using a deep learning technique. The authors propose a Convolutional Neural Network (CNN) architecture to extract characteristics from sensor data and achieve precise localization of the UAV within indoor settings. The paper [14] describes a method for indoor UAV localization that uses Wi-Fi fingerprinting and supervised learning methods. They gather Wi-Fi signal strength data and apply machine learning techniques to pinpoint the UAV's position precisely.

In this project, we use LoRa technology with machine learning techniques to predict the location of UAVs in indoor environments as discussed before.

III. Experimental Testbed and Dataset

At the beginning of the project, we designed and fabricated LoRa-based reference and target nodes. The design and fabrication of LoRa-based reference and target nodes allowed us to adapt and optimize the hardware, particularly for our project's needs, providing accurate and efficient data collecting for indoor localization. Then, RSSI data will be collected on the second floor of the ‘Suranimala Building’(the selected indoor environment area). The deployment of LoRa-based reference and target nodes enabled us to gather accurate RSSI data on the second story of the 'Suranimala Building,' offering a targeted dataset for the indoor environment of interest. Moving and reference nodes are as follows.

Fig. 2. Moving node

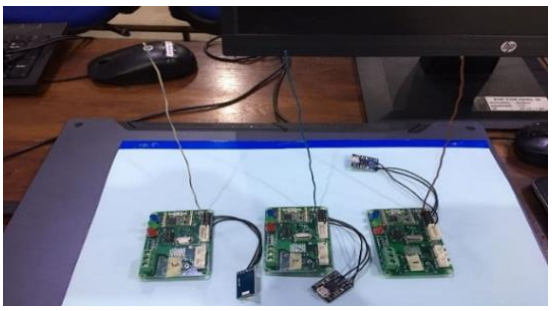

Fig. 3. Reference nodes

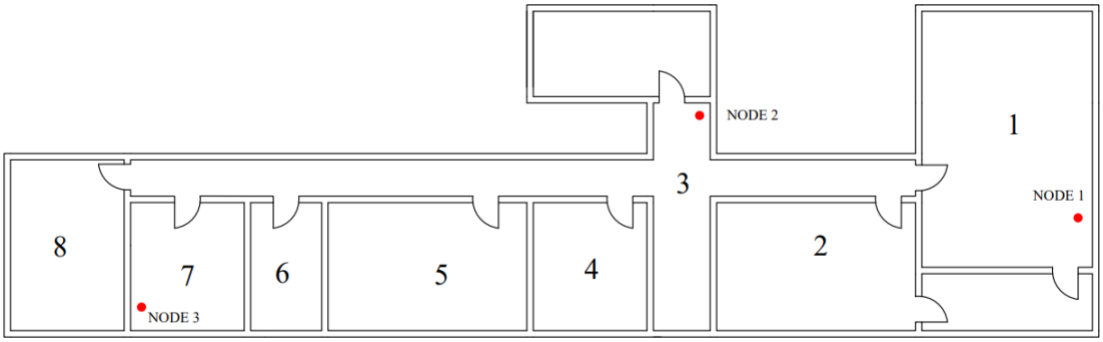

Fig. 04. Floor plan of the indoor environment

In this project, we used an indoor area within a building and chose eight distinct positions on one of the building's floors (called Suranimala building). By selecting these eight varied spots on a certain level of the Suranimala building, we hoped to capture various situations and spatial differences inside the indoor environment for comprehensive research and assessment in our project. Above Fig.04 is a sketch of the indoor environment we used.

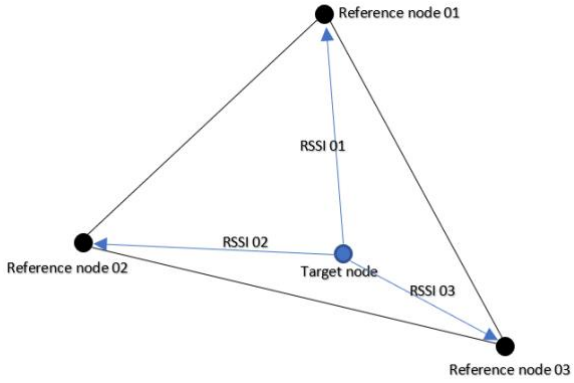

Fig. 5. Triangular method for the reference nodes

We placed the three reference nodes inside the building in a triangle arrangement. According to peer-reviewed studies, the triangle approach was the most effective method for obtaining more accurate data. In addition to implementing the best practices recommended by peer-reviewed studies[15], the three reference nodes were strategically positioned inside the structure in a triangular configuration to enable triangulation-based localization techniques, which were intended to improve the accuracy and reliability of the data collected. The figure mentions them as Node 1, Node 2, and Node 3.

The locations of the nodes are as follows.

TABLE I. LOCATIONS OF THE NODES

Node	Location
1	Lecture Theater A
2	Open Area
3	Computer Engineering Laboratory

The locations and location IDs we used are as follows.

TABLE II. LOCATIONS AND LOCATIONS ID'S

ID	Location
1	Lecture Theater A
2	Lecture Theater B
3	Open Area
4	CCNA Laboratory
5	Lecture Theater C
6	QA Laboratory
7	Computer Engineering Laboratory
8	Computer Science Department office

RSSI data were graphed for each reference node to measure variation between the eight classrooms. You can see those graphs in the following figures (Fig. 6, Fig. 7, and Fig. 8).

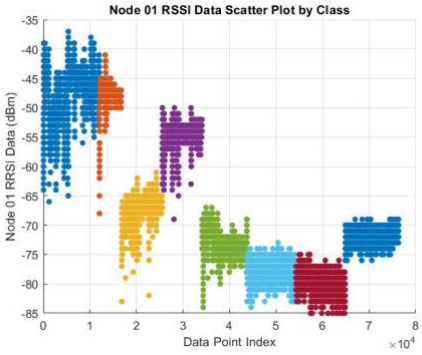

Fig. 6. RSSI data scatter plot by classes for Node 01

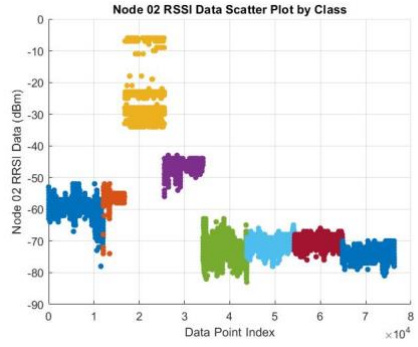

Fig. 7. RSSI data scatter plot by classes for Node 02

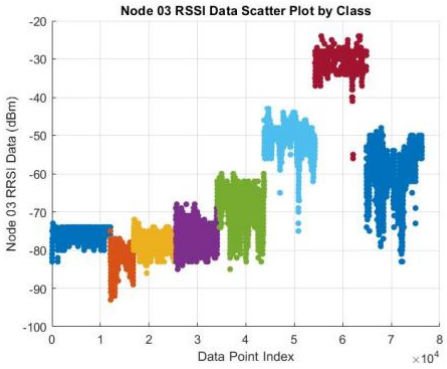

Fig. 8. RSSI data scatter plot by classes for Node 03


Fig. 9.1. Reference node 01 in lecture theater A

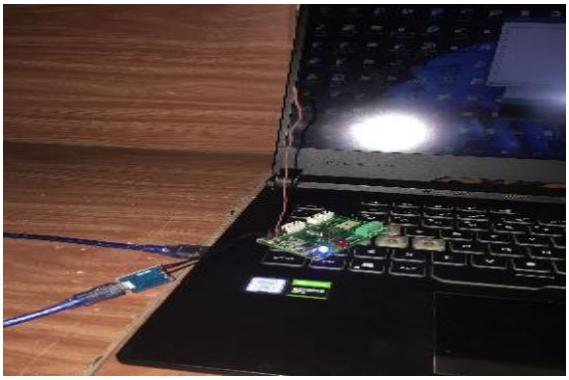
Fig. 9.2. Reference node 01 in lecture theater A


Fig. 10.1. Reference node 02 in open area

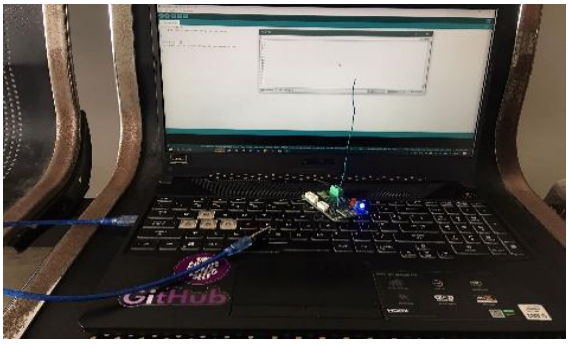

Fig. 10.2. Reference node 02 in open area


Fig. 11.1. Reference node 03 in computer engineering laboratory


Fig. 11.2. Reference node 03 in computer engineering laboratory

The images above represent the three distinct sites where the reference nodes were fixed. These carefully selected points act as secure anchors inside the system, giving a consistent frame of reference for subsequent analysis. Positioning these reference nodes is critical for appropriately measuring the system's behavior and dynamics under diverse situations.

IV. Model Training

We used Supervised Learning machine learning algorithms to develop a model to work in this project. We tested with different ML algorithms and got metrics like accuracy, precision, recall, and f1 score as the results for the collected dataset. SVM Classifier, Naive Bayes, kNN Classifier, Random Forest Classifier, Decision Tree Classifier, and Gradient Boosting(ensemble learning) are the Supervised Learning machine learning algorithms we used to take the above results. The performance of the machine learning algorithms was evaluated using the metrics obtained to determine their efficacy in the specific project. These metrics provide helpful information about the algorithms' ability to identify and predict the expected results accurately. The performance of each evaluated algorithm varied, emphasizing the significance of picking the best algorithm for the individual project needs. Examining several algorithms enables a thorough study, which aids in the decision-making process for model selection and future enhancements.

TABLE III. Results for the Matrices

Algorithm	Accuracy	Precision	Recall	f1
SVM Classifier	97% (0.975197618225773)	0.975197618	0.975983075	0.975137382
Naive Bayes	97% (0.976236239734405)	0.977850854	0.97782008	0.977720322
kNN Classifier	98% (0.98169666258955)	0.983258433	0.982793815	0.983024892
Random Forest Classifier	98% (0.982526646863533)	0.983864206	0.983502461	0.983678867
Decision Tree Classifier	98% (0.9824392800978)	0.983647066	0.983589162	0.983614874
Gradient Boosting(ensemble learning)	98% (0.983880831731609)	0.985112829	0.984620901	0.984844812

V. Results and Discussion

The results of the Supervised Learning algorithms serve as the foundation for creating the model in this project, allowing informed judgments about algorithm selection and future changes to maximize its performance. Tab. 3 reveals that all approaches provide a high accuracy percentage for all of the ML algorithms we tested but with tiny differences. As a result, we can select the Gradient Boosting algorithm as the most effective approach for the particular hardware needs based on the performance of the various Supervised Learning algorithms on hardware devices. However, after applying filtering techniques to the acquired dataset, we should repeat this step. We hope to modify and improve the performance of the selected Supervised Learning algorithms by combining filtering techniques into the acquired dataset, establishing a robust and accurate model for UAV localization in indoor situations.

VI. FutureE Works

In this project, we have used LoRa reference and target nodes to develop a system for position tracking of UAVs in an indoor environment. We have collected an RSSI dataset in this project and used supervised learning algorithms to predict the location. The ML algorithms we have used are only SVM, Naïve Bayes, kNN, Random Forest, Decision tree, and Gradient boosting. Other supervised learning techniques could be used for this project as well. In addition, we only experimented on a single building floor. This LoRa approach might be used in a building with several floors with the same structure. Also, if the UAV is outside the building, this may be tried for indoor and outdoor surrounding environments simultaneously and predict its location. Exploration and experimentation with additional supervised learning techniques, expanding the experiment to multiple floors within a building, and extending the LoRa approach to indoor and outdoor environments can all lead to more robust and versatile UAV position-tracking systems in various settings.

VII. Conclusions

We presented an experimental low-power RSSI data-gathering testbed based on LoRa wireless technology that will aid in the design of indoor positioning systems in this paper. GPS is a locational solution that does not function well indoors. Wi-Fi's constrained sensing range makes it unsuitable for large-scale indoor applications. LoRa is suggested over currently used techniques because of its high sensing capacity. Microcontrollers were used to design reference and target nodes to reduce energy and costs. The three reference nodes are located in different places inside the building in a triangular position and the moving node was fixed to the UAV and located in eight different places on the same floor of the building to collect. The dataset was developed with the RSSI

data collected with this test bed. The dataset obtained from the low-power LoRa-based RSSI data-gathering testbed provides valuable insights and potential for developing accurate and cost-effective indoor positioning systems, taking advantage of the benefits of LoRa technology, energy-efficient microcontrollers, and strategically placed reference and target nodes for comprehensive data collection.

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2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

Enhancing Educational Resilience: Applying the Flipped Classroom Model in Sri Lanka's Challenging Economic and Political Landscape

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***Abstract*—Recent economic and political instability in Sri Lanka has had a profound impact on various sectors, notably the education sector. Evidenced by the temporary closure of schools, universities, and higher education institutions, as well as the postponement of national examinations, the adverse effects of Sri Lanka's economic and political turmoil on education have been unmistakable. This educational upheaval mirrors challenges faced during the COVID-19 pandemic. In response to these challenges, some educational institutions in Sri Lanka have turned to the Flipped Classroom Model (FCR) as a means of mitigating these disruptions. This study aims to investigate the influence of the Six Hat Model, which encompasses six main directions of learning, on the quality of the FCR model. The research adopts a descriptive design and focuses on undergraduate students within the Faculty of Business Management at Sri Lanka Technological Campus. Data were collected through structured questionnaires from 141 undergraduate students. The findings of the study underscore the necessity for strengthening three critical facets: addressing challenges (black hat), acknowledging emotional factors (red hat), and promoting self-directed learning (white hat) within the Six Hat Model when enhancing the quality of the FCR model, particularly in the context of economic and political instability. Additionally, the study emphasizes the importance of staff preparation and training to optimize the outcomes of the FCR model in these challenging circumstances.**

Keywords—Six thinking hats, flipped classroom model, economic and political instability, higher education, learning directions

I. INTRODUCTION

The COVID-19 pandemic has presented formidable challenges to industries worldwide, forcing organizations to transition from conventional to online platforms in order to adapt to the new normal [1]. This shift encompasses the emergence of virtual organizations, flexible working hours, telecommuting, and remote work capabilities. Technological advancements have played a pivotal role in facilitating business operations through various digital platforms [2]. Among the various sectors affected, the higher education industry has seized the opportunity to enhance the teaching and learning experience. Globally, traditional classrooms have given way to flipped classrooms, characterized by the utilization of synchronous and asynchronous learning methods—a defining feature of the new normal in higher education [3]. While technology-enabled education does present its share of challenges, it has proven to be a valuable asset for digital learners.

In Sri Lanka, many higher education institutions swiftly transitioned to online operations shortly after the initial wave of COVID-19, which occurred between January and March 2020. Lectures were conducted virtually instead of physical classrooms, with the Learning Management System (LMS) serving as the primary point of interaction between teachers and students, aside from direct contact hours. To enhance student engagement, self-guided materials, videos, quizzes, practice questions, video recordings, and other resources were incorporated into the learning process [4]. Examinations were also conducted online, with rigorous technological supervision. This transformation from traditional to online platforms, necessitated by the limitations imposed by COVID-19, has become a gradual and transformative trend in many higher education institutions.

During the COVID-19 pandemic, the sudden need for remote work arrangements posed an unexpected challenge to SLTC, an institution that had not previously embraced online teaching. To address this challenge, the university swiftly implemented a well-planned strategy for emergency remote teaching, as outlined by [5]. This strategy incorporated both asynchronous and synchronous online learning methods, with the LMS serving as the platform for asynchronous learning and Zoom LEARN facilitating synchronous interactions. The readiness and proficiency in these technological tools emerged as a critical factor influencing teachers' engagement in the work-from-home setting, as highlighted by [6]. While many Sri Lankan universities eventually returned to traditional synchronous learning in physical classrooms as the pandemic decreased, SLTC chose to take a different path. They introduced a novel pedagogical approach known as the flipped classroom (FCR). The FCR model blends elements of asynchronous and interactive

synchronous learning strategies, offering a dynamic and engaging learning experience. This shift towards the FCR model was inspired by the positive outcomes observed during the online learning phase necessitated by COVID-19. Online learning was found to enhance students' independent learning abilities and foster self-regulated thinking, surpassing the benefits of traditional learning modes.

The FCR strategy incorporates several key elements to enhance the learning experience. Content delivery within the modules is facilitated through a LMS utilizing both synchronous and asynchronous methods. Teachers have the flexibility to choose their preferred mode of delivery, allowing synchronous learners to engage in real-time via Zoom LEARN, while recorded online lecture sessions are stored on the LMS for future reference. Alternatively, those opting for asynchronous learning can upload pre-recorded videos or PowerPoint presentations. Students are encouraged to ask questions and clarify concepts via chat (Discussion Forum) in the LMS. After each lesson, synchronous discussion sessions take place, both in face-to-face settings and online via Zoom. These discussions were introduced to provide students with additional opportunities for interaction with their instructors. To ensure continuous improvement, student feedback is collected mid-semester and at the end of the semester, guiding ongoing development of the process. This comprehensive approach aims to create an engaging and effective learning environment that meets the diverse needs of students.

The adoption of the FCR model at SLTC in response to the new normal situation has sparked criticism among both staff and students for various reasons. One primary point of contention revolves around the quality of online education integrated into the FCR model. Furthermore, there has been debate surrounding the FCR model's efficacy in developing students' thinking skills. De Bono's Six Thinking Hats model provides an analytical framework to examine this matter [7]. This model encompasses six directions of thinking, each associated with a colored hat, including Information (white hat), Feelings (red hat), Thinking about Thought (blue hat), Creative (green hat), Challenges (black hat), and Constructive (yellow hat). While some researchers [8] have discussed various FCR methods and their effectiveness, there has been limited exploration of the direction of thinking within this context.

The study recognizes the need to explore both the quality and the directions of thinking in the FCR model. Consequently, the study aims to address this research problem, with the objective of finding the impact of the six hats of the FCR model on quality of educational delivery through FCR. The significance of this study lies in its potential to improve the quality of academic delivery, considering the six thinking hats within the FCR model. Additionally, it contributes to the theoretical aspect by delving into the relatively under-researched area of academic delivery from a quality perspective.

II. Literature Review

A. FCR Model

The FCR is a student-centered learning method consisting of two parts interactive learning activities during the lesson and individual teaching based on the computer out of the lesson [9]. FCR model has also been identified as 'what is done at school done at home, homework done at home completed in class' [10]. Key information is offered by the resources and materials shared by the facilitator before commencing the session. Activities including problem-solving, discussion and brainstorming are performed during class time and the facilitator has the role of guide in the synchronized process. In flipped classroom approach, Facilitators prepare videos about the subjects before teaching. Students are then expected to refer to the videos before starting the session. The lesson starts with short questions and answers. If there are points in a lecture that are not understood, they are explained. During class time, students are allowed to learn by discussing. However, in the traditional approach teaching the subject takes the most of course time [10].

The advantages of the flipped classroom derive from both an individual learning process and the in-class learning process. The advantages that expressed are; students can access lecture videos whenever and wherever they want and it provides students to learn at their speed [11]. The students educated with this approach are encouraged to think both within and outside of class [12]. Further, it includes both active learning and the advantages of individual learning [9]. Despite these advantages, flipped classroom approach provides students more time to make inventive research [13].

Even with these advantages, a number of scholars have also pinpointed its limitations. The difficulties that may occur when the students do not watch the videos before coming to the class [14]. Facilitators may have difficulty understanding whether the students do their responsibilities out of class or not [15] From the facilitator’s side not preparing or broadcasting lecture videos but preparing in-class activities and integrating them into flipped classroom approach is also regarded as one of the main limitations [16]. The flipped classroom model is developed pedagogically by using educational technologies to create the most efficient time for class activities. Students can utilize technological equipment, develop their abilities, create interactive discussion conditions, and discover different learning methods with different learning activities.

Flipped classroom approach increases students’ active engagement in the class [17]. Classroom engagement, which is one of the vital influencers to create an effective learning environment, is regarded as an indicator of student achievement [18]. In its simplest forms, classroom engagement can be identified as the active involvement of the student in learning activities [19]. On the contrary, classroom engagement as the willingness of the student to engage in daily school activities, such as continuing to school, doing homework, and listening to the teacher in class [20].

The low level of classroom engagement creates negative effects on course performance and the learning process [21]. In this context, the importance of active and collaborative learning, academic activities, effective communication with the teacher, and educational experiences within the scope of classroom engagement [22]. Students’ classroom engagement levels are evaluated by affective engagement,

cognitive engagement, and behavioral engagement [21]. In the classroom, affective engagement refers to the positive feelings of students such as interest, excitement, and amusement. Cognitive engagement refers to the processes such as meaningful processing, strategy use, concentration, and metacognition. Behavioral engagement refers to observable behaviors such as asking questions, being active in team-works and completing tasks without delay [19].

A. Six Hat Model

Education consists of two main goals which are transmitted to students: the first goal, what to think, is the transmitting of subject matter and acquiring basic knowledge; the second, how to think or critical thinking, involves cognitive process instruction [23]. In the process of understanding critical thinking, many definitions and descriptions have been given to the term [23] [24]. While some theories use the term interchangeably with higher-order thinking skills (HOTs) [23], others believe that critical thinking is included in higher order thinking skills along with creativity and other thinking skills [24]. Nonetheless, common elements have been distinguished such as information processing, analysis, problem-solving, and metacognition [25]. Often the second goal, how to think, is so subtle, that instructors and students fail to recognize and realize its absence [23]. Thankfully, Bloom's Taxonomy in 1950 clears this vagueness as it acts as a base for critical thinking by providing a framework for classifying statements of what we expect or intend students to learn as a result of instruction [26]. Thinking skills in both the original taxonomy and the revised Taxonomy by Anderson (1990) are organized into six levels, from the most basic to the higher order levels of thinking [27]. While the original taxonomy develops in the cognitive domain, the revised taxonomy consists of a two-dimensional framework: knowledge and cognitive processes [26]. As such, Anderson explains that the shift of the six categories from noun to verb forms is to reflect the different forms of thinking as an active process [27].

Similar to the transmission of what to think and how to think, Bloom's taxonomy has two tiers namely lower order and higher order thinking skills; where the lower order levels act as a base for the higher order thinking skills which are focused on the top three levels of the Taxonomy: analysis, evaluation, and creativity [24]. Higher order thinking skills are thus grounded in the lower order skills namely discriminations, simple application and analysis, and cognitive strategies, and are linked to prior knowledge of subject matter content [28]. By successfully applying these skills, King et al explain that it will result in explanations, decisions, performances, and products that are valid within the context of available knowledge and experience, and promote continued growth in these, as well as other intellectual skills [28]. While Bloom's Taxonomy has been the mainstay in higher level thinking skills [29], often referenced to connect critical thinking and creative thinking [24], the 'Six Thinking Hats' is a thinking tool which De Bono's describes as a simple, effective parallel thinking process that helps people be more productive, focused, and mindfully involved [7]. In applying the Six Hats, students are stimulated to think and control their learning [30] as it requests specified modes of thought which allow the thinker to simplify thinking by dealing with points consecutively and allows a switch in thinking as mentioned [31]. Hart and Nolan emphasize that the purpose of employing thinking tools in the inquiry classroom is for facilitators and students to work with and as inquirers to confront their notions and ideas about the way the world works and about the meaning of teaching and learning as a process rather than mere knowledge acquisition [31]. In contrast to Bloom's taxonomy, the Six Hats has no fixed order [32]. However, when applying this parallel thinking skills concept, thinkers are required to look in the same direction at any one point, though the direction can be changed [31]. As ideas are encouraged to be explored from a variety of angles, it provides a space for critical thinking and creativity [32] [24].

The need of modern education context expects students to have the ability to think, and to enable them to solve problems they may face in their academic career and make decisions. There is a strong emphasis on infusing thinking skills into the curriculum such as recalling, classifying, comparing, inferring, generalizing, evaluating, experimenting, and analyzing. The work of Edward de Bono has given educators a repertoire of a unique strategies to use with their students, namely, Six Thinking Hats. Six Thinking Hats is an internationally recognized tool to teach thinking in all content areas. A simple and practical way of carrying out parallel thinking is the Six Thinking Hats method. Although students may have completely dissimilar ideas at the beginning, they can present similar ideas objectively with a change in the hats [7]. The Six Thinking Hats teaching technique provides students with specific thought patterns and allows them to observe topics from different angles. This method is of fundamental significance because it provides us, for the first time, with a practical method of constructive thinking. The Six Hats can be used individually or in combinations and for specific results, the hats can be ordered and used deliberately.

The white hat (Neutrality, Think about the facts). White hat thinking is a way of asking for facts and figures to be put forth neutrally. It encourages the thinker to separate what is fact and what is interpretation. The more information people have the better will their thinking be and the more appropriate their actions [31]. This hat is usually used at the beginning of a session as a background for the thinking that is going to take place as it provides a more rational approach. The white hat seeks out information that is missing and known.

The yellow hat (Optimistic, think about the positive aspects of a topic). The yellow hat focuses on identifying the values, advantages, or benefits of something [33]. It is the optimism hat. Everyone in turn has to say what is good about the proposal, or idea. Even if one thinks the idea does not work well, he has to find some redeeming qualities and good points about it [34]. People put on yellow hats to find ways to solve the problem; because they are optimistic. They are creative when they wear their yellow hats. Their thinking revolves around how it can be done to enjoy the benefits. Without the yellow hat, creativity is almost impossible because we would never see the benefits of an emerging idea.

The black hat (Critical, judgmental, and think about the negative aspects of a topic). The black is the cautious hat, judging the 'fit' of the facts, experience, system, law, policy, and ethics. It denotes constructive criticism. This angle of thinking explores the problem with a topic or proposal; identifies flaws, risks, and obstacles; and exercises judgment and caution [35]. The black hat is for critical thinking and risk assessment. This is the logical positive. Why something will work and it will offer benefits? It can be used in looking forward to the results of some proposed action but it can also be used to find something of value in what has already happened. The black hat is the hat of survival. Overuse of the black hat may lead to an unhealthy cynicism where people only seem to find fault with everything.

The red hat (Emotions, Examine a topic through emotions and feelings) Red hat symbolizes feelings and hunches. A red hat is a color of emotion and passion. Logic is not required [36]. Too often we let our emotions make our decisions. Red hat gives us a separate context to state our true feelings and then explore their implications. Red hat thinking can praise or criticize an idea based on raw, subjective feelings [37]. What are my feelings now? What does my intuition tell me? Simply put Red hat thinking looks at a topic from the point of view of emotions, feelings, and hunches. The Red hat requires no justification. Thinkers are encouraged to contribute to the emotional aspects of the problem or idea under discussion [35]. With the red hat, people have to say how this proposal makes them feel emotional. For example, some might say they feel threatened or scared by this idea. Others might say they feel excited [34].

The green hat (Creativity, New ideas, Brainstorming, and Prediction). The green hat symbolizes creative thinking. It gives the go-ahead to generate alternatives and explore ideas. It is in nature that a green hat thinker would say, 'We need to explore new possibilities' [38]. It encourages the use of creative solutions to problems. It seeks to answer questions such as 'Are there other ways we could do this? What else could we do?' Green hat thinking offers sufficient solutions to the black hat thinking problems. 'What should you do then with the ball? Play the ball outside the house!' It is used to explore, investigate, decide, and, in so doing, give way to freewheeling thinking [36]. Green hat of thinking provides provocations, new ideas, and outrageous alternatives, with no effort to criticize or evaluate the merits of these ideas [37]. One can use green hat thinking to shake things up by making turbulence with novel ideas while setting off in a new direction. This hat of thinking involves the cognitive processes of identification, clarification, generation of solutions, predicting consequences, and evaluation of solutions [33].

The blue hat (Reflect, think metacognitive, and try to grasp the big picture, a summary of a topic). The understanding and reflection are denoted by the blue hat. It focuses on outlining the problem and what is being thought about. The blue hat can be used both at the beginning (for planning) and at the end (for summarizing) of each session for process control [33]. Wearing the blue hat is like being in the sky above, looking down on a situation, and planning for the best way to think about it. It is a helicopter view of the big picture. It manages the thinking process by setting the agenda and deciding on the next step. It wraps up the process by making the decisions, summarizing, and concluding on the action taken. De Bono emphasizes the need for a thinker to be able to look at his or her thinking. In fact, he should be able to reflect on the thinking he has used in performing a thinking task. The Blue hat thinker organizes the thinking itself and calls for the use of other hats [31].

Thus, the study focuses on testing the following hypotheses:

HA1: The white hat has a positive impact on the quality of the FCR model

HA2: The red hat has a positive impact on the quality of the FCR model

HA3: The black hat has a positive impact on the quality of the FCR model

HA4: The yellow hat has a positive impact on the quality of the FCR model

HA5: The green hat has a positive impact on the quality of the FCR model

HA2: The blue hat has a positive impact on the quality of the FCR model

III. METHODOLOGY

Research philosophy as a system that contains beliefs and assumptions on knowledge development [39]. This is about what a researcher is doing when conducting research or developing new knowledge in a certain field. Researchers are required to make a number of various assumptions at every stage of research [40] in the form of epistemological assumptions reflecting the assumptions regarding human knowledge, ontological assumptions reflecting the realities encountered in the study and the axiological assumptions reflecting the researcher's own value system influences for the research process. Since the research question of this study is to evaluate the quality and the direction of the FCR model this study owns a quantitative aspect and hence follows a positivism philosophy along with a deductive approach. The research strategy of this study is survey research, and the context includes the SLTC.

The study's focus centers on the SLTC, specifically targeting the undergraduate student population within the Faculty of Business Management. The sample comprises 150 undergraduate students from the SLTC Faculty of Business Management, and the sampling method employed is convenience sampling. To gather responses, an online questionnaire was distributed among the selected sample units.

The conceptual framework of the study is depicted in Fig. 1. Accordingly, the six hats: information, feelings; thinking about thought, creativity, challenges, and constructive design guidelines represent the study's independent variables whereas the quality of the academic delivery via FCR represents its dependent variable.

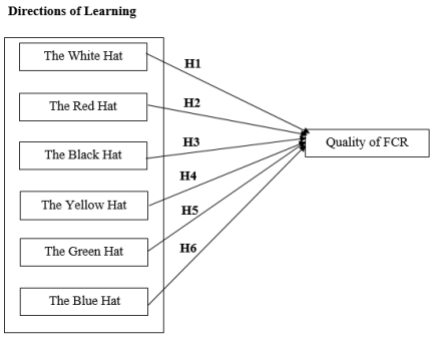

Fig. 1. Conceptual framework of the study, (Source: Author constructed)

IV. Results and Discussion

Initially questionnaires were distributed to a group of 150 undergraduate students within the Faculty of Management at SLTC. Following the removal of outliers and a thorough data cleaning process, the dataset was refined to include 141 valid responses for subsequent analysis. The collected data underwent analysis using IBM SPSS (International Business Machines Corporation's Statistical Package for the Social Sciences), involving several steps.

Descriptive analysis was used to examine the demographic profile, as summarized in Table I. Among the 141 students, 74 were male, and 67 were female. The majority, approximately 83%, fell within the age category of 19-23 years. Furthermore, 42.6% of the students were in their first year of university, while 35.5% were in their second year of studies.

TABLE I. Demographic Profile

demographic profile variables	*Respondents' details*	*Number of respondents*	*Percentage of respondents*
Gender	Male	74	52.5
	Female	67	47.5
Age	<18 Years	1	0.7
	19-23 Years	117	83.0
	24-28 Years	19	13.5
	>29 Years	4	2.8
Year of Study	01st Year	60	42.6
	02nd Year	50	35.5
	03rd Year	20	14.2
	04th Year	11	7.8

Source: Survey Data

Reliability in the context of this study, assesses the consistency of responses provided by survey participants. To measure the internal consistency and reliability of the variables, a calculation involving the coefficient alpha (Cronbach's α) was performed, along with the examination of item-total correlations for each variable. Following the criteria set [41]; a Cronbach's alpha coefficient of 0.7 or greater is considered acceptable. The results of the reliability tests, including the final Cronbach's alpha coefficients for each variable are presented in Tab. 2.

TABLE II. Cronbach's Alpha Reliability Table

Variables	*Number of items*	*Cronbach's alpha*
The White Hat	4	0.748
The Red Hat	7	0.890
The Black Hat	4	0.887
The Yellow Hat	4	0.895
The Green Hat	5	0.950
The Blue hat	5	0.961
Quality of FCR	4	0.928

Source: Survey Data

All the Cronbach's alpha coefficient values for each variable exceed 0.7, indicating that the survey instrument is reliable, and there is a high level of internal consistency.

The Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy, assesses the ratio of correlations and partial correlations [42]. This metric helps determine the extent to which correlations are influenced by the shared variance across all variables rather than specific pairs of variables. KMO values range from 0.00 to 1.00 and can be computed for both the total correlation matrix and individual measured variables. It is generally desirable to have an overall KMO value of $\geqslant$ 0.70, [43]. Conversely, values below 0.50 are typically considered unacceptable (Hair et al., 2010). Such values suggest that the correlation matrix cannot be effectively factorized.

The Kaiser-Mayer-Olkin (KMO) and Bartlett's test were used to examine the appropriateness of the factor analysis (see Table III).

TABLE III. Cronbach's Alpha Reliability Table

Variables	*Kaiser-Meyer-Olkin Measure of Sampling Adequacy.*	*Bartlett's Test of Sphericity*		
		Approx. Chi-Square	*df*	*Sig.*
The White Hat	.592	114.497	3	.000
The Red Hat	.876	575.074	21	.000
The Black Hat	.822	309.555	6	.000
The Yellow Hat	.827	360.297	6	.000
The Green Hat	.894	705.169	10	000
The Blue hat	.911	801.641	10	.000
Quality of FCR	.851	458.787	6	.000

Source: Survey Data

The KMO values for five variables are close to 1 (>0.822), and one variable has a KMO value exceeding 0.5. This suggests a significant degree of information overlap among the variables and the presence of strong partial correlations. Consequently, conducting factor analysis seems plausible. The Bartlett test assesses sphericity, indicating the proximity of the correlation matrix to an identity matrix. Significance values below 0.05 for all variables in Bartlett's test indicate that the data is suitable for factor analysis.

A normality test was conducted to assess whether the data followed a normal distribution, and the results are

presented in Table IV. According to the Kolmogorov-Smirnov test (with a significance level of $P < 0.05$), it was determined that the data for the dependent variable do not exhibit a normal distribution.

TABLE IV. TESTS OF NORMALITY

	Kolmogorov-Smirnov[a]		
	Statistic	***df***	***Sig.***
QLTM	.236	141	.000

a. Lilliefors Significance Correction

Given that the data did not conform to a normal distribution, the Spearman's rank correlation coefficient (Spearman's rho) was used to assess the relationships between variables. The results of these correlation tests can be found in Table V. It's noteworthy that all six thinking hats, representing six distinct learning directions, displayed strong and positive correlations with the dependent variable, which pertains to the quality of FCR. This suggests a significant association between these thinking hats and the quality of FCR.

TABLE V. SPEARMAN'S RHO

	QLTM		
WHM	Correlation Coefficient	.505**	Strong positive correlation
	Sig. (2-tailed)	.000	
RHM	Correlation Coefficient	.565**	Strong positive correlation
	Sig. (2-tailed)	.000	
BKHM	Correlation Coefficient	.465	Strong positive correlation
	Sig. (2-tailed)	.000	
YHM	Correlation Coefficient	.637**	Strong positive correlation
	Sig. (2-tailed)	.000	
GHM	Correlation Coefficient	.695**	Strong positive correlation
	Sig. (2-tailed)	.000	
BHM	Correlation Coefficient	.687**	Strong positive correlation
	Sig. (2-tailed)	.000	

***. Correlation is significant at the 0.01 level (2-tailed).*

TABLE VI. HYPOTHESIS TESTING

	Standardized Coefficients	t	Sig.	Hypothesis
	Beta			
WHM	.089	1.250	.213	HA1 Rejected
RHM	-.075	-.791	.430	HA2 Rejected
BKHM	.006	.075	.940	HA3 Rejected
YHM	.239	2.699	.008	HA4 Accepted
GHM	.306	3.306	.001	HA5 Accepted
BHM	.330	3.560	.001	HA6 Accepted

a. Dependent Variable: QLTM

Regression analysis was used to evaluate the research hypotheses. As indicated in Table VI, three of the alternative hypotheses (HA1, HA2, and HA3) are rejected, as their associated p-values exceeded 0.05. Conversely, the remaining three hypotheses (HA4, HA5, and HA6) are accepted, as their p-values are less than 0.05.

However, the fundamental premise of a 'thinking skills' approach to education is rooted in the idea that the quality of students' lives and their learning experiences is intricately linked to the caliber of their thinking [25]. While some theories use the term interchangeably with 'higher order thinking skills' [23], others employ it to encompass not only higher order thinking skills but also creativity and various other forms of thinking skills [24]. Additionally, there are arguments positing that thinking is a holistic activity [25]. Nevertheless, a concern that traditional education, focused on prescription, often funnels students through a series of narrow educational pathways, limiting their capacity for 'possibility thinking' as they grow [7]. To address issues related to emotions, helplessness, and confusion that can arise during critical thinking, the six thinking hats model was developed.

Based on the findings, the blue hat (Control of Thinking) is the most important hat and has a strong positive impact on the quality of the FCR model. Blue hat thinking contributes to critical thinking and problem-solving by involving higher-order thinking and cognitive control. The teaching methods in the FCR model help with focus, summarization, conclusion drawing, and action planning. Further, access to videos and materials in the Learning Management System (LMS) aids student reference.

Following the blue hat, the green hat emerges as the next most crucial element that contributes to improving the quality of the FCR model. The green hat symbolizes creative critical thinking and problem-solving. Within the context of the FCR model adopted by SLTC, students are motivated to generate novel ideas and concepts. This motivation is fostered through innovative learning approaches, self-study methods, creative assessments, and other strategies that not only boost creativity but also enhance the overall quality of the FCR model. Moreover, the green hat effectively addresses the challenges associated with the black hat while reinforcing the values represented by the yellow hat. In the FCR model, students are initially provided with a hint or starting idea, which they then use as a catalyst for their own thinking. They actively contribute their ideas to the collective pool of insights generated by the entire class, fostering collaborative and creative thinking.

Yellow hat thinking brings a sense of optimism and a resolute determination to succeed into the critical thinking and problem-solving process. When students put on the metaphorical yellow hats, they embark on a quest to discover solutions to problems, driven by their inherent optimism. The FCR model serves as a platform that facilitates critical thinking and problem-solving, particularly within the context of problem-based learning, allowing students to harness their positive outlook as they tackle challenges.

In contrast, the white hat, which is primarily concerned with gathering factual information in an objective manner, does not appear to significantly impact the quality of the FCR model. White hat thinking is instrumental in identifying the necessary information and subsequently in the collection of that information, involving both individual and

collaborative efforts in the search for data. To enhance the effectiveness of white hat thinking, it is recommended to adopt student-centric approaches that empower students to engage in self-directed learning, such as self-study initiatives or think-pair-and-share sessions. Typically, white hat thinking is employed at the outset of a session, providing a foundational background for the subsequent thinking processes. Its primary purpose is to uncover missing or existing information, making it an essential component of the overall problem-solving approach.

Similarly, the red hat, which encompasses emotions, feelings, hunches, and intuitions, does not seem to significantly influence the quality of the FCR model. Emotions associated with the red hat may include joy, fear, anger, jealousy, and sorrow. Nevertheless, within the framework of the FCR model, there is an opportunity to stimulate positive emotions through a range of teaching and learning methods. These methods can include synchronous and asynchronous approaches, such as visualizations, case studies, group activities, and more. By incorporating these strategies, the FCR model can actively engage students and cultivate positive emotional responses, enhancing the overall learning experience.

The black hat has no impact on quality of the FCR model, whereas SLTC should focus more on the black hat. It implies challengers that the critical, judgmental and think about the negative aspects of a topic. The black hat describes as the hat of survival, hence overuse of the black hat may lead to an unhealthy cynicism where people only seem to find fault with everything. To sustain the black thinking hat, the lecturer can ask students to check for evidence that supports what they articulate. They should check for the truth or validity of logical arguments raised. They should examine suggestions made to see if they are feasible, given the prevailing circumstances. They have to think deeply about the potential consequences of their actions before making judgments.

The black hat, which is designed to provoke critical judgment and investigate into the negative aspects of a subject, does not appear to significantly impact the quality of the FCR model. However, it is suggested that SLTC should pay more attention to the black hat thinking approach. The black hat serves as a mechanism to challenge ideas and engage in critical analysis, providing a balanced perspective on issues. It's often associated with survival thinking, but it's essential to avoid its overuse, as it can lead to an unhealthy cynicism where individuals habitually find fault in everything.

To effectively incorporate the black hat thinking, instructors can encourage students to seek evidence supporting their arguments, assess the validity of logical reasoning, scrutinize the feasibility of suggestions in the given context, and contemplate the potential consequences of their actions before making judgments. By striking a balance and using the black hat carefully, students can foster a more comprehensive and critical understanding of the subjects they are studying.

V. Conclusion

Findings of the study highlight the varying impacts of different thinking hats within the quality of FCR model. While the blue, green and yellow hats significantly enhance the FCR model's quality, the white and red hats have a lesser influence on quality of FCR model. Notably, careful use of the black hat is recommended for balanced critical analysis in FCR model.

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2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

Development of Graduate Employability Skills Through Speaking Strategies

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***Abstract*—With the socio-economic changes in the modern world, employers look for practical skills in an employee rather than cognitive skills. Having a college degree with higher achievements is no more considered as an assurance to secure a job without having proper applied skills. In order to survive in a competitive job market, the employees need to have mastered both professional and communication skills during their undergraduate programmes. In an undergraduate language learning classroom, subtle communication skills can be significantly improved by using the four skills of language such as reading, writing, listening and speaking. Out of all the skills, speaking strategies used in the classroom can be considered as an effective method of developing these communication skills. This study aims at finding the strategies that can be used to develop undergraduate soft skills and the method of transforming those soft skills into employability skills. Through a qualitative approach by collecting responses of 20 university teachers in both public and private higher education institutes in Sri Lanka chosen through simple random sampling, this study illustrates the results analysed through thematic analysis about the key speaking strategies that drive soft skill development and the manner in which the soft skills are translated to employability skills.**

Keywords—Graduate employment, soft skills, employability skills, speaking strategies

I. INTRODUCTION

In the emerging business and corporate world, high skilled employees are mostly sought out by employers. In the way towards their professional excellence, soft skills play a key role as much as the hard skills are considered as a prerequisite in performing the job responsibilities. Similar to the rest of the world, Sri Lankan employers are no exception in seeking the best talents who are equipped with both hard skills and soft skills from higher education institutions across the country. While all graduates fulfil the basic, fundamental requirements for being eligible to secure a job with their degree certifications, there is a considerable minority of graduates who can comply with the value sets and organizational profiles of the employers. It is the "soft skill gap" that marks the borderline of graduates being employable or unemployable.

The ESL (English as a Second Language) curriculum of Sri Lanka comprises of developing competence pertaining to the four skills of language: Reading, Writing, Listening and Speaking while the eight (08) National Goals and the seven (07) competencies designed towards achieving the National Goals, aim at producing a competent individual with an apt language proficiency. At university level, the graduate profiles of each higher education institute provide a comprehensive overview of the profile of a skilled graduate, graduating with a respective degree along with the mastery of hard skills and soft skills. However, only a significant number of graduates become employable by meeting the requirements of the organizations while recent studies have shown a vast disparity between the employer expectations and graduate competence due to the soft skill gap.

As a solution to the concurrent soft skill gap, this study intends to find mechanisms of developing employability skills of undergraduates by using speaking strategies performed in ESL classrooms. As a productive skill, speaking involves the development of soft skills in an individual along with the personality development and development of cognitive skills.

A. Graduate and Employment Statistics

According to the latest statistics of the University Grants Commission, in 2021, the graduate output consists of 76.6% of Bachelor Degree holders and 23.4% of Postgraduate Degree holders which is a total of 36,012. In addition to that, 7,802 Open University graduates and 6,802 graduates from the External Degrees have also graduated in the year 2021, making a total of 50,616 graduates excluding the graduates of private universities. Unfortunately, more than 50% of the graduates (25,704) have stayed unemployable during the year. Out of the number of unemployed graduates, 43.9% have graduated with an Art degree whereas the rest graduated with other degrees. Thus, the unemployment of graduates remains as a significant concern in the public and private sector of Sri Lanka as the graduates lack skills and expertise to be eligible in securing a job.

In 2021, the employed population in Sri Lanka is categorised under three major industry groups namely, Agriculture (27.3%), Services (46.7%) and Industries (26.0%), while the majority of employed population in all three industries contribute as employees and own account workers while the minority is either an employer or a contributing family member. Furthermore, Sri Lanka Labour Force Survey (2021) shows the highest percentages of employed population in occupations such as elementary occupations, skilled agricultural, forestry and fishery workers, craft and related trades workers, services and sales workers respectively while a lesser percentage of employed population engaged in occupations where they serve as Professionals, Managers, Senior Official and Legislators and Clerical Support workers.

B. Employability Skills

In the aftermath of the COVID-19 pandemic, the higher education institutions are undergoing an unprecedented pressure unlike the previous years, in terms of producing quality graduates who are competent in knowledge, skills and attitudes that fit workplaces. According to previous literature, communication skills, interpersonal skills, teamwork and leadership skills and problem-solving skills have been notable among the widely prominent soft skills required by modern day workplaces although "soft skills" have different skill sets depending on countries and subject disciplines. In a study conducted in Sri Lanka by recording employers' perspective on valued skills and attributes expected by students of Commerce and Management discipline, with reference to five large scale organizations varying from local to Multi-National Corporations (MNC), four key elements have been highlighted. The skill categories include workplace skills, people skills, applied knowledge and personal knowledge. The study concludes by underlining that those skills are opted by employers as the prerequisites of employability skills [1].

A recent study discusses ten factors that are essential in graduate employability including highest significance recorded in communication skills ($F = 21.34$, $P < 0.001$) while team work skills ($F = 11.26$, $P < 0.001$) were the next priority. Other employability skills involved stakeholder management skills, decision making skills, cross cultural competency, core business skills, personal and behavioural skills, digital competencies, domain knowledge and customer orientation respectively from the highest significant employability skill dimension to the lowest significant employability dimension [2].

Among the notable employability skills needed in graduates, communication skills play a significant role. A framework formed by a group of researchers containing a taxonomy of employability skills is classified into four components: cognitive skills, methodological skills, social skills and subject-specific skills. The study further shows that the knowledge and content learned through studies should be applied to solve practical problems while this approach enhances the subject-specific understanding along with improving creative thinking, analytical, problem solving, decision making, communication and management skills [3].

Apart from that, a research study conducted by Boston University and University of Michigan's School of Business have concluded that employees with a training in their soft skills are 12% more efficient and productive than the employees without a proper training in soft skills whereas another study conducted by Stanford Research Institute and Carnegie Mellon Foundation proved that a long term success in a job resulted in a proper capacity of soft skills (75%) whereas the rest of the 25% was from technical skills. With the reference to the importance of soft skills in a long term professional career, it is highlighted that the communication skills are its fundamental attribute [4].

C. Communication Strategies for Employability Skill Improvement

Reference [4] discusses how hard skills and soft skills have its unique potentials in work environments. Hard skills help the individuals to acquire a job whereas soft skills help in assuring the employability. Under communication skills that is vital in soft skill development, verbal and written communication are integral components. Competence in verbal communication is included in the correct use of grammar, tonal variations and language eloquence, while non-verbal communication traits such as correct posture, appearance, head and eye movements and body contact also reflect an individual's character. Furthermore, the researcher concludes in the research that English language skills have become an integral component in bridging the gap between undergraduate communication skills and employability. The study further provides methods of enhancing the soft skills of undergraduates through project based learning, classroom activities and teaching methods.

The role of language in developing communication skills in a way that the undergraduates become competent in their soft skills is undeniable. In order to communicate with the supervisors, managers and subordinates effectively without any misunderstanding or misinterpretation, verbal communication skills are essential. As much as the receptive skills of language (reading and listening) contribute in improving the soft skills, the productive skills (speaking and writing) are also equally important. In an academic environment, the foundation for effective soft skills training should be laid in order to groom the undergraduates to fit into their future workplace. Thus, techniques used in classroom environment in language learning can be directly applied to develop communication skills of undergraduates to become employable in their future workplaces.

D. Speaking Strategies

In any language, speaking is considered as a basic skill as it is acquired ever since the birth of child which starts from cooing and babbling of sounds. Until a child reaches an age, where he/she is able to develop other skills pertaining to reading, listening and writing, they continue to acquire the words that they hear in their surroundings. This is applicable to a first language acquisition or a second language acquisition. While English language is known as the global link language due to the universality if the language, in Sri Lanka, English is taught as its second language. Majority of children in urban areas of the country are exposed to the language from early childhood while a considerable minority has their first encounter with the language at primary level of education.

In an ESL (English as a Second Language) classroom, an equal weightage is given in improving the four skills of language. While other skills focus on improving basic grammar, vocabulary, writing structures and comprehension skills, much of the soft skills are improved through speaking skills. Researchers have shown findings about the use of speaking strategies that enhance soft skills in undergraduates through the language curriculum and other subject-integrated modules at higher education institutes. Those strategies involve the use of role plays, classroom presentations, task-

based practical work and reflections on learning experience as tools for developing undergraduate employability skills [5].

III. METHODOLOGY

This study intends to find answers for the following research questions:

(i) What are the unique speaking strategies which can be used to improve soft skills of undergraduates?

University teachers can implement various strategies to develop competences related to soft skill development of undergraduates. With the use of emerging technologies and digital tools, speaking related tasks can be taught in an advanced and a creative way. Moreover, it should be noted that the traditional methods of teaching speaking lessons for the undergraduates are outdated as the modern generation of learners have vastly different expectations and approaches towards learning skills of a language. Thus, the respondents of this study share an in-depth understanding about their students with the experience they have gathered through modern teaching strategies.

(ii) How do the speaking strategies transform an undergraduate to be successfully employable?

The soft skills embedded in the speaking strategies directly help the undergraduates to develop their communication skills which in return increase the probability of them being employable in a relevant profession in future. Each speaking strategy comprise of at least one significant soft skill and most of the soft skills are applicable to the modern-day workplaces and thus, are included among the 21st century skills.

A. Participant Profile

For this study, 20 university teachers from nine (09) higher education institutes of Sri Lanka, both in public and private sector, teaching introductory, intermediate, academic and business English programmes for undergraduates pursuing multi-disciplinary study programmes were selected through simple random sampling. All the university teachers had an experience with one or more years of teaching undergraduates at the same university while eight (08) teachers had their minimum level of education with a Bachelor's degree with English as a compulsory subject in the degree programme whereas the rest had a Master's degree in either English, Linguistics or Teaching English as a Second Language.

B. Instruments

As this study uses a qualitative research approach that involves getting opinions and views of the participants, an online questionnaire is shared among the participants after affirming their voluntary, active participation in the data submission. In order to avoid any breach of privacy and an honest contribution in providing accurate information, the participants' preference to take part in the study was recorded.

C. Data Collection Procedure

As primary research data, data collected through the online questionnaire were considered. The questionnaire framework consisted of two parts including fifteen (15) comprehensive questions in which eight (08) questions targeted at deriving speaking strategies and seven (07) questions aimed at re-directing those speaking strategies into employability skill transformation. As secondary research data sources, information found through extensive literature from credible research articles, government statistics reports and journal articles were used for the study.

D. Data Analysis Procedure

By using an inductive approach to analyse the data collected through primary and secondary sources, this study entails the thematic analysis to find answers for the research questions by deriving common themes after decoding the similar phrases in the detailed responses provided by the respondents. All the codes that were related to the research questions are thus, incorporated into a common theme. The derived themes were then transferred in a visual thematic map in order to ease the process of drawing links between each theme. Although many themes were highlighted, the themes which lacked data to support arguments were discarded.

IV. RESULTS

The responses for all the questions in the questionnaire provided by the 20 respondents were carefully evaluated and key words, phrases and ideas were coded in order to derive common themes. In a separate data sheet, the responses of the participants pertaining to each question were clearly tabulated so that similarities and contrasts can be drawn by comparing the 20 responses. Afterwards, common ideas and views were highlighted by using a unique colour coding system in order to link the relationships between each highlighted component.

Soft Skills through Speaking Strategies

Although a considerable number of soft skills can be mastered through other skills of a language, speaking skills are an integral component in any language that caters to developing many soft skills. As today's undergraduate population consists of individuals belonging to Generation Z, the traditional teaching and learning approaches are transformed into a modern and computer-assisted learning and a teaching method. Therefore, traditional teaching approaches like audio-lingual method, oral drills or loud reading which involved practicing pronunciation, tonal variations and intonations through constant repetitions are replaced by modern approaches such as Communicative Language Teaching (CLT), Task-Based Language Teaching (TBLT), Total Physical Response (TPR) and the Silent Way that indirectly encourage the students to participate in practical language tasks. Creative and interactive activities embedded in these indirect teaching approaches not only engage the students in classroom activities by physically being active, but also the tasks allow the students to be autonomous with the minimum intervention of the teacher. The role of the student is therefore, to be an active participant in the activities despite being a mere listener and a follower like in a traditional classroom.

Usage of creative digital tools in conducting speaking related tasks was a priority inside modern classrooms as they created a lively and an interactive work environment for the undergraduates. The higher education institutes have advanced resources and more digital tools unlike in school classrooms and those tools are effectively used to cater to the undergraduate learning expectations. Interactive speaking activities that involved projecting a clue in the board with a picture or a video clip related to the lesson, for the students to interpret and present their opinion, giving speech topics followed by a video, to be delivered in the form of both prepared and impromptu speeches and showing an inspirational video to get their interpretive thoughts are among many strategies to be used in enhancing soft skills. These activities not only create an enthusiasm among the undergraduates in learning and acquiring soft skills, but also, they arouse curiosity to explore more about the subject.

(I) Audio-Visual Tools

All participants shared their experiences in using digital tools to conduct speaking sessions. Among the methods they used to conduct speaking sessions through digital tools were, picture presentations, videos, game-based learning platforms, interactive presentations, question and answer sessions and guest lectures. Those methods were coded by extracting the ideas in their responses while a common theme of audio-visual tools was identified.

Using audio-visual tools is an efficient way of maximising the output of students as the students are inspired by modern lecture delivery methods. The students' enthusiasm and active participation can be encouraged by allowing them the chance to showcase their speaking competency by using digital tools. While the teachers use these creative tools to achieve the intended learning outcomes, the students gradually improve their soft skills over the course of the lecture duration.

Unlike in traditional classrooms where communication skills are improved by word drills, repeated pronunciations and speeches, audio-visual tools are more appealing to the learners. The speech extracts from the respondents identified as Kamalini, Thushara, Prathiba and Kelum[1], it was clear that they have implemented a student-centred approach in developing the speaking skills.

TABLE 1. AUDIO-VISUAL TOOLS

Extracts	Codes	Theme
Usually, I take the advantage of using the digital resources to initiate speaking activities. I show a video or a picture related to the lesson and get the students to speak. - *Kamalini* -	•Interpretive thoughts •Picture descriptions	Audio-Visual Tools
As I mostly teach the Gen Z students, they like to listen to speeches or watch videos on forums like TedTalks or Toastmasters and speak about them, so I show them an inspirational video. I also use apps like Kahoot to follow up their understanding of the task. - *Thushara* -	•Prepared and impromptu speeches •Game-based learning platforms	
I use presentations as a strategy to develop speaking skills of students. I have also used guest lecture sessions (both online and physical). - *Prathiba* -	•Class presentation •Guest lectures	
I always ask the students an ice-breaker question like "What is happening around the world these days?" and then show them a video or an article related to the question so that they can express their views/ideas about it. - *Kelum* -	•Q and A sessions	

[1] Pseudonyms are assigned for the respondents to ensure their privacy

(II) Guided Learning Tools

Although all the respondents have disregarded traditional approaches of teaching in delivering speaking tasks, the majority of the respondents incorporate some effective case practices of traditional teaching into modern teaching. For speaking strategies such as group discussions, storytelling, information gap identification, scavenger hunts, dramas and role plays, a minimal level of teacher's intervention is needed to a certain extent. The teacher's role is that of a facilitator or a mentor, rather than being an active participant in instructing and directing the students. The principal behind these speaking strategies is that, student-centered learning is encouraged with a minimum supervision of the teacher.

TABLE 2. GUIDED LEARNING TOOLS

Extracts	Codes	Theme
I like to create a competitive yet a challenging environment for the students. I usually group them and give them a task where everyone has to speak. - *Madhuri* -	• Group discussions • Story telling	Guided Learning Tools
After introducing the concept and guiding the students with vocabulary related to the lesson, I introduce them an interesting game or an activity along with some clues for them to complete the task by communicating with each other. -*Thushara* -	• Information gap activities • Scavenger hunt	

I give instructions for the students to create a mini-drama or a role play based on the lesson as I can evaluate their competency through a practical task like that. - *Pawan* -	• Dramas • Role play	

[2] Pseudonyms are assigned for the respondents to ensure their privacy

In order to develop soft skills through speaking strategies, the students should be given the maximum advantage to interact in the classroom. The teacher needs to strategically design the tasks in allocating more time for the learners to engage in activities.

The responses of Madhuri, Thushara and Pawan[2] showed the positive changes implemented in teaching strategy in order to encourage the independent learning with a minimal supervision of the teacher. Those approaches helped to make the learners inquisitive as they explore innovative forms to develop their competencies in speaking.

(III) Peer Learning Activities

Among the speaking strategies used to develop soft skills of undergraduates, pair work and group work are opted by many respondents. As a mechanism of improving student participation, evaluating their performance and testing whether the learning outcomes are met, activities that aim at developing peer interaction are chosen. Through these activities, the students get the chance to use their creativity in producing a unique output by following the general guidelines given by the teacher. Therefore, the output of each pair or the group is vastly different from that of the others and the students who observe another pair/group activities have the chance to assess their peers while understanding the new vocabulary related to the subject. Debates are among another strategy that involves mutual interaction and coordination among group members to improve speaking skills as the language needs to be spontaneously in use while in debates. Through interviews and mock interviews which can be done as role plays where one student takes the role of the interviewer while the other takes the role of the interviewee in asking questions pertaining to a specific subject, soft skills can be enhanced. Teachers can practise techniques in facilitating the scaffold learning of students by gradually reducing the support given to them while letting the students to develop themselves with their peers' assistance. This strategy drives positive instincts among the students as their independent learning is encouraged. Peer assessment is another strategy that provides the opportunity for the students to learn from each other as the students receive a performance evaluation from their peers. The evaluation can be done through a question and an answer session allocated for few minutes at the end of the tasks. As the common theme that draws the connection between each response, activities that encourage peer interaction is recorded through the participant response analysis.

Soft Skill to Employability Skill Transformation

As a result of the globalisation, workplaces have also changed the way they operate, in catering their products and services. It has been a challenge to the organizations to find the best talents to drive their sustainability, while they also have some higher expectations about the employees that they are going to recruit. Among the mostly requested skillsets by employees, is the communication skills. Through the previously discussed speaking strategies, there are soft skills that can be directly recognised as higher order employability skills. When the students engage in speaking activities in the classroom, communication skills are developed along with the soft skills like creative thinking, logical thinking, leadership and teamwork.

In the way towards developing an undergraduate with the relevant skillsets needed for the future world of work, university teachers have a role to play. For that, the language teachers need to assess the soft skills that can be improved through each teaching strategy. Through the responses recorded through the questionnaire used for this study, some key soft skills that can be transformed into employability skills were identified.

(I) Digital Skills

Digital skills are an integral part of having an individual equipped with essential employability skills. Speaking strategies such as presentations, dramas and role plays develop the competency in Information and Communication Technology (ICT) and computer skills as the students explore the available resources in developing their work. With the development of Artificial Intelligence used in multi-disciplinary areas to fulfil tasks, the students can resolve their confusions or gather insights relevant to the subject areas. Other important digital skills such as the basic knowledge in designing and graphics are also required in presenting the output of a speaking activity by using audio-visual tools.

As many workplaces require the basic digital literacy in their job specifications to perform tasks, classroom speaking activities that integrate these skills can be advantageous. The post-pandemic work environment entirely transcended the traditional work setup even by replacing jobs that could be easily handled with digital tools. Having a basic understanding on technical support tasks and digital marketing through creative tools, are other skills that can be developed through the speaking strategies. These skills indirectly contribute in an individual's future workplace whether they become employees in an organization or establish their own organization, as they are some of the basic 21st century skills mastered by an individual.

(II) PR (Public Relations) Skills

Many speaking strategies used in a classroom help in an individual's personality development process. When individuals have an outgoing personality, they develop a certain level of confidence to interact with others. Soft skills help to develop confidence and autonomy which is deliberately imbued through speaking strategies. Prepared and impromptu speeches along with individual and group presentations improve the students' confidence by

eliminating their fear of public speech or appearance. Leadership and teamwork is tested by group activities in the classroom where the students have to delegate the responsibilities among themselves to bring a quality output. Social skills such as ethics, integrity, empathy, emotional balance and networking is shown through dialogues, role plays and debates as they bring the students' honest opinions on their perception, cultural understanding, values and attitudes. These character traits are reflected through an individual, starting from the job screening process while those traits indirectly impact on routine practices in a workplace.

(III) Learning and Development Skills

Storytelling helps an individual's capacity building while it awakens their critical and analytical mindset. Moreover, storytelling activities which are done by associating them with real-life tasks and situations improve the logical reasoning which is also an important employability skill. Communication skills such as attentive listening and clear articulation are improved through interviews as interview facing techniques are also mastered as soft skills. Language games improve collaboration with peers while debates and dialogues on controversial topics improve conflict resolution and problem-solving skills.

Factors like relevance and interest need to be considered before implementing speaking strategies. The delivered content needs to be relevant, interesting and encouraging to the audience in order to grasp the intended outcome. The teacher needs to instil a sense of personal development being in progress while the students engage in tasks that provide them the opportunity to develop their crucial soft skills.

Through speaking strategies that help in students' learning and development, other language components such as basics of grammar, pronunciation and vocabulary are also developed. By integrating timely relevant occurrences around the world in creative speaking tasks such as debating and interviewing, above soft skills can be developed to a greater extent. The respondents[3] have also implemented such creative strategies to improve the speaking skills of students.

TABLE 3. LEARNING AND DEVELOPMENT TOOLS

Extracts	Codes	Theme
Challenging tasks motivate the students in exploring new arenas. Therefore, I give them treasure hunts where they can collectively complete the task through clear arguments, conversations and reasons. - *Malini* -	• Critical thinking • Analytical thinking • Logical reasoning	Learning and Development Skills
I give them practical tasks. For example, if they want to improve their telephone skills, I ask them to contact a hotel, restaurant, bank or any other institution to make an actual inquiry. - *Nalin* -	• Communication • Collaboration	
By taking examples from home news or world news where a problem/conflict is concerned, the students can be given the chance to investigate how the situation has been managed or how it can be managed. - *Kamani* -	• Conflict resolution • Problem solving	

[3] Pseudonyms are assigned for the respondents to ensure their privacy

V. CONCLUSION

Based on the findings after analysing primary and secondary data sources, it was evident that soft skills play a key role among the employability skills sought out in an individual. Compared to the hard skills that are gained through the subject knowledge of core modules related to a specific degree, soft skills are unique in such a way that it involves a great exposure, consistent practice and a positive attitude to develop those skills. Any graduate can become employable with the lack of soft skills but they can not secure their employability. Malperformance, demotivation and turnover are the repercussions of not being equipped with soft skills.

In a language learning classroom, soft skills are indirectly improved by incorporating those skills in to the main spheres of language learning. Unlike in other three skills such as reading, writing and listening, speaking skills give more focus to the soft skill development aspect. These skills are embedded in the speaking component while some strategies are used to signify the relevance of soft skills in future work environments. Such strategies involve the use of audio-visual tools such as presentations, videos, picture/poster presentations, game based learning platforms, speeches, guest lecture sessions and Q and A sessions, guided learning tools such as group discussions, storytelling, treasure hunts, dramas and role plays along with peer learning activities such as debates, interviews, scaffold learning techniques and peer assessments.

Furthermore, it was evident that these strategies develop soft skills which are mandatory employability skills. Thus, a relationship was drawn in transforming these soft skills into skills that help graduates to become employable by securing their long-standing employability. As a result, digital skills such as literacy in IT, computer skills, designing and graphics, PR skills such as confidence, leadership, teamwork and social skills together with learning and development skills like critical thinking, analytical thinking, logical reasoning, collaboration, conflict resolution and problem solving are noted among the key employability skills.

Interestingly, all of these skills are among the essential 21st century skills that an individual should be equipped with.

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2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

Optimizing the Fabric Flows during the Warehouse Receiving Process: A Simulation Study in Sri Lankan Fabric Industry

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***Abstract*—Sri Lanka has made significant contributions to the global fabric manufacturing industry, particularly in terms of quality production, diversification, and sustainability. One critical aspect of the fabric industry is the warehouse receiving process, which involves the inspection, sorting, and storage of incoming greige flows into the warehouses. Nevertheless, the optimization of the warehouse receiving process remains a relatively unexplored area of research. Accordingly, this study was undertaken to reduce work in progress and optimize the warehouse receiving process of a highly reputable fabric manufacturing company in Sri Lanka. The selected warehouse suffered from significant work in progress and long waiting queues, posing major drawbacks. The existing system had only one data entry counter, a team for carrying and storing greiges enabling the system to behave as an integration of a single server queuing system. This system was observed for four working shifts within two consecutive days and analyzed using Rockwell Arena software version 16 by utilizing a sample comprising 273 observations for each parameter. It was identified that 93 greiges work in progress and lengthy waiting queues were the major issues. Recommendations were defined under three possible improvements. They were increasing the resources at the data entry counter, eliminating temporary storing areas, and disaggregating the existing team into more empowered teams. Among the defined recommendations, a model with improvements except adding another data entry counter was the economically feasible model. The optimized model resulted in reducing work in progress up to 59 greiges. Thus, eliminating temporary waiting areas and optimal use of the staff was the conclusion for reducing the work in progress. Additionally, it recommends conducting further longitudinal analysis to obtain optimal results and refine the proposed strategies.**

Keywords—Arena, queuing simulation, greige, waiting time, work in progress

I. INTRODUCTION

Greige, regularly known as fabric, is a combination of natural and synthetic fibers or threads made through a common process that includes weaving, sewing, holding, felting, and turfing. Greige or fabrics are commonly used in an assortment of items, including clothing, domestic furniture, and industrial materials [1]. Greige materials are made in large amounts and conveyed to textile mills around the world to encourage preparing for the reason of creating a tremendous range of garments [2]. This allows for more enhanced productivity in material fabricating as textile manufacturing firms can focus on coloring, printing, and wrapping up instead of beginning from scratch with raw materials [3]. In general, the greige manufacturing industry is a significant portion of the textile industry [4].

Commitment of Sri Lanka on the Greige manufacturing industry: Sri Lanka has made noteworthy commitments to the worldwide greige manufacturing industry, especially in terms of quality production, diversification, employment generation, trade profit, and sustainability. The industry in Sri Lanka is known for creating high-quality fabrics that meet worldwide standards and has contributed intensely to modern innovation and production processes [5]. Generally, Sri Lanka's greige manufacturing industry is a crucial contributor to the worldwide textile industry and has made a difference in promoting economic development, employment, and sustainability within the nation.

A. Greige Flows in Warehouse Receiving Processes of the Selected Organization

The selected organization is one popular Greige manufacturer in Sri Lanka. It manufactures Greige textiles in large quantities and then delivers them to the textile and garment manufacturers worldwide including the local apparel manufacturing giants. This allows for greater efficiency in textile manufacturing as the firms can focus on dyeing, printing, and finishing rather than starting from scratch with raw materials. Therefore, the organization provides its products worldwide for producing high-quality fabrics that meet international standards and has invested heavily in modern technology and production processes.

Warehouse management in the selected organization involves daily operations running in the warehouse. Amongst, receiving and organizing the related space, scheduling of respective employees, managing inventory, and fulfilling orders are vital. Thus, effective warehouse management expects to optimize these processes while integrating many operations and working together to improve its performance. Considering the usual practice, the Warehouse receiving process is identified as the first and the most important step in warehouse management. It involves the inspection, sorting, and storage of incoming fabric greige flows in warehouses. Productive and profitable receiving processes are basic for the fabric industry to meet customer demand, reduce lead times, and minimize costs.

- In this warehouse receiving process, it was not monitored hence; any service discipline or labeling system indicating such receiving was not available. Thus, identifying the respective products was very hard. This caused many products to be retained in the warehouse for a long time without further processing.
- Forming of many waiting lines was found in the warehouse. Checking the quality of products manual and the absence of any service disciplines were identified as major causes for the above problems. They laid many barriers to a smooth warehouse operation.
- Accumulation of defects, disposals, and unnecessary amount of inventories at each work station in the warehouse created ineffective space utilization. Thus, low visibility was noted in the selected warehouse receiving process. Thereby, the organization could not identify the moving and non-moving inventories. This caused creating much waste in the warehouse while taking much additional time and labor to find required items among those inventories.
- Moreover, the warehouse operation of the fabric manufacturing industry involves several processes, people, and strategies to ensure its effective performance. But, in the Sri Lankan context, the industry of warehouse management also encounters numerous challenges. Amongst, skills gap among the employees, low visibility in the warehouse, delays in warehouse processes, and accumulation of unnecessary amount of inventories and defectives are vital.

The accessed empirical literature provided evidence for the existence of the above problems in many contexts. Amongst, the following were highlighted.

A warehouse receives manufacturing products or commodities from suppliers and distributes them to wholesalers or customers [6]. The first operation in the warehouse is receiving. This procedure begins with a notice of the arrival of goods. The process of unloading, counting, identifying, quality control, and goods acceptance (incoming inspection) is associated with a particular type and quantity [7]. Planning and controlling in warehouse management have been explored by professionals from both the arts and sciences. Nonetheless, a robust fundamental theory for warehouse design technique is still absent [8]. Each day in the warehouse, this work's receiving, data entry, and storing operations are all conducted simultaneously, and the arrival of greiges, inspecting, unloading, and racking storage are the procedures in the unloading system [9]. The Fabric Greige Flows during the Warehouse Receiving Process have not received significant attention in the existing literature, despite the numerous studies on queuing systems in different contexts.

Nonetheless, there are no solid core theory or simulation studies for warehouse design techniques. Simulation is the process of developing computer models of real or hypothetical systems that are used to run numerical experiments under various situations to acquire a better knowledge of the system [10]. The application of simulation modeling in the manufacturing industry is well-explained by those who emphasized that the majority of applications are for control and production planning analysis.

Therefore, this research aimed to address this gap by carefully investigating the current structure and performance of fabric greige flows during the warehouse receiving process. Accordingly, the objectives of this study were to;

- Model and analyze the receiving and storing of greiges in a finished goods warehouse.
- Examine potential strategies for optimizing the waiting times and wait times of data entry and storing operations in the warehouse.
- Accordingly propose viable solutions to enhance the overall efficiency of warehouse operations.

II. Methodology

A. Theoretical Model

Queueing theory is a well-known mathematical method used in operations management for investigating waiting lines and WIPs. Queueing theory is a well-known mathematical method used in operations management for investigating waiting lines and WIPs [11].

Little's rule states that the average length of a queue (L) and the typical length of time a customer spends in a system (W) are inversely related. The average length of the queue (L) can be calculated using the average number of customers in the queueing system (Ls) and (Lq). The rate of arrival for the units to the system is λ. The average amount of time a client spends in a system (W) can also be stated as the sum of their time spent in line (Wq) and their time spent in the queueing system (Ws).

The general model marked by

$$M/M/S:GD/\infty/\infty \quad (1)$$

can be used to define a queueing system that has multiple servers, an unlimited waiting room size assuming that the storing capacity is very large compared to the entities arriving in the system, and an unlimited population. Here, the letter M stands for Markov process, S is the number of servers, and GD is the general discipline, which means that

the services are offered on various service disciplines such as FIFO/LIFO, etc. This study is focused on the analysis of the complex queuing system comprising multiple queuing

Nevertheless, theoretically, the basis for the queuing system follows the above assumptions. When a system of queuing system is analyzed, the entire system is an integration of various critical components, Rockwell Arena software provides the simulation platform for analyzing the system virtually with the feature of running the actual system in a simulated environment in a speed manner with utilizing object path simulation, routine path simulation, realistic 2D and 3D animation capabilities, graphical use interfaces built around SIMAN language, common flowchart modules such as 'Create, Process, Decide, Dispose, Batch, Separate, Assign, and Record'. Create a module to simulate the arrival greiges into the system. The process module represents the core of the system that simulates the steps and major actions done to the arrived entities into the system. The decide module introduces the decision points or conditions in this simulation such as returning criteria in the process of returning the damaged greiges to the QC department. The batch module is used for grouping the greiges and processing them as a batch [12]. Assign module deals with the resource allocation for handling specific greiges or processes based on predefined rules and priorities. The dispose module is used to exist the entities where they have completed their tasks or left the process [14].

Rockwell Arena software provides both options which are module-based model building and animated-based model. To model a non-stationary time-dependent queueing system with limited resources and solve queueing problems using Arena, researchers must rely on their knowledge and experience in identifying the appropriate and relevant system parameters and making modifications to these system parameters through trial and error [15].

The Fabric Greige Flows amid the warehouse receiving process have not received noteworthy consideration within the existing literature, despite the various considerations on queuing systems in different contexts. Subsequently, this research aimed to address this gap by analyzing the current structure and execution of fabric greige flows during the warehouse receiving process and proposing viable solutions to improve the overall efficiency of warehouse operations. In this study, the primary objective is to model and analyze the receiving and storing of greiges in a finished goods warehouse. The simulation experiments were utilized to examine potential strategies for optimizing the waiting times and wait times of data entry and storing operations within the warehouse while minimizing operating costs.

B. Data Collection

The study focused on the finished goods warehouse receiving process of a leading greige manufacturing company in Sri Lanka, with observations limited to two normal working days from 8.00 am to 10.00 pm, encompassing both peak and non-peak hours. Data was collected by recording 321 observations on various types of parameters. Parameters related to service provisions, parameters related to route times, and the parameters related to waiting times of the system are the basic types of variables that have been observed in this study. There were two major service provisions in this system identified as:

- Data entry process
- Storing process.

There were four major routes included in this system identified as:

- R1 - Route time from the corridor area to the data entry area
- R2 - Waiting time (R2) from data entry to the temporary warehouse area
- R3 - Route time from the temporary warehouse area to the storage rack
- R4 - Route time (R4) for returning greiges from the data entry area to the Quality Control (QC) department which is not a major analysis component in this study (in minutes)

Two waiting times were identified within the system as follows:

- Waiting time before the data entry process
- Waiting time before the storing process (in minutes)

Subsequently, data were collected for the following variables through the observations;

i. Number of Rolls

ii. Arrival of number of greiges per each trolly was averaged as 11 greiges.

iii. Inter-arrival time of greiges (in minutes)

iv. Route time (R1) from the corridor area to the data entry Area (in minutes)

v. Route time (R4) for returning greiges from the data entry area to the Quality Control (QC) department (in minutes)

vi. Decision criteria on data entry or moving to Quality control (QC) where the criterion is that 5% of arrived greiges at the warehouse entrance are returned to the QC department

vii. Waiting time before the data entry process (in minutes)

viii. Service provision time for the data entry process (in minutes)

ix. Route time (R2) from data entry to the temporary warehouse (in minutes)

x. Waiting time before the storing process (in minutes)

xi. Route time (R3) from the temporary warehouse area to the storing rack (in minutes)

xii. Service provision time for the Storing process (in minutes).

The following assumptions were made in order to collect and analyze data:

i. Greiges are not moved to the queue until their details are entered.

ii. Unlimited number of arrivals of greiges

iii. Data entry services are provided according to the FIFO (First In - First Out) method.

iv. There are no work shifts among the workers.

v. While the model is running, the employees aren't provided with breaks.

C. Data Analysis

The collected data comprising 321 observations for each variable was processed using SPSS Software version 21 to clean the data and to eliminate any outliers that deviated significantly from the rest of the dataset due to various measurements and unexpected behaviors of the system. After the data cleaning the sample was reduced up to 273 observations for each variable or parameter. The data was then analyzed using Rockwell Arena Student Version 16 software, with its Input Analyzer feature used to examine the data distribution of the observed variables. The results obtained from the input analyzer were utilized to generate Tab. 1.

TABLE I. PROBABILITY DISTRIBUTIONS OF OBSERVED VARIABLES

Variable	Distribution
Number of rolls	3.5+26*BETA(2.33,2.42)
Inter arrival time of greiges (mins)	TRIA(0.4, 22.5, 45)
Waiting time before data entry process (mins)	TRIA(5, 18.2, 21)
Data entry process service provision time (mins)	WEIB(6.58, 3.48)
Waiting time before storing process (mins)	NORM(6.55, 1.49)
Storing process service provision time (mins)	TRIA(1, 15.3, 21)
R1	1+2*BETA(1.58, 0.48)
R2	TRIA(1, 2.51, 3.23)
R3	TRIA(2, 5.44, 6)
R4	TRIA(5, 13.2, 14)

Number of rolls per each lot of arriving to the system has followed a Beta distribution where the alpha parameter is 2.33 and beta parameter 2.42 suggesting that the distribution is negatively skewed. In addition to that, mean value of number of greiges arriving was 11 per trolly. This mean value for number of greiges arrival has been considered in further system analysis of this study. Inter arrival time of greiges which a primary parameter in the queuing system has obtained a triangular distribution with the minimum possible value is 24 seconds and, maximum possible value is 45 minutes suggesting that the inter-arrival time of greiges cannot exceed 45 minutes and most likely value is 22.5 minutes considering that most common or expected time between arrivals is 22.5 minutes.

Greiges are waited at the corridor of the warehouse before scanning following a triangular distribution where the minimum waiting time before the data entry process is 5 minutes, most likely waiting time is 15.2 minutes and waiting time cannot exceed 21 minutes. Route time from the corridor to the data entry area has followed a Beta distribution where the alpha parameter is 1.58 and the beta parameter 0.79 suggesting that the distribution is positively skewed. Route time of moving returning greiges to the QC department has followed triangular distribution with the minimum possible value is 5 minutes, and maximum possible value is 14 minutes suggesting that the inter-arrival time of greiges cannot exceed 14 minutes and most likely value is 13.2 minutes considering that most common or expected time between arrivals is 13.2 minutes.

Service provision time for the data entry process has followed a Weibull distribution with the shape parameter 6.78 minutes suggesting the distribution is positively skewed and the scale parameter is 3.68 minutes suggesting that a moderate amount of variability in the service provision time for the data entry process. Route time from the data entry area to the temporary warehouse area has followed a triangular distribution with the minimum possible value is 60 seconds and, the maximum possible value being 3.23 minutes suggesting that the inter-arrival time of greiges cannot exceed 3.23 minutes and most likely value is 2.51 minutes considering that most common or expected time between arrivals is 2.51 minutes.

Greiges are waited at the temporary warehouse area before moving into racks and the waiting time has followed a normal distribution with a mean of 6.55 and a standard deviation of 1.49 minutes indicating that the waiting time may be 6.55 ± 1.49 minutes. Storing process service provision time has obtained a triangular distribution with the minimum possible value is 60 seconds, and the maximum possible value is 6 minutes suggesting that the inter-arrival time of greiges cannot exceed 6 minutes and the most likely value is 5.44 minutes considering that the most common or expected time between arrivals is 5.44 minutes.

Further analysis was conducted using the Arena model and animated model features by utilizing various modules such as ‘Create, Process, Decide, Dispose of, Batch, Separate, Assign, and Record’.

D. Model Development

The selected warehouse suffered from significant work in progress and long waiting queues, posing major drawbacks. The existing system had only one data entry counter, a team for carrying and storing greiges enabling the system to behave as an integration of single server queuing systems with the parameters of unlimited population size and limited waiting room capacity. To address these issues, three possible improvements were identified and categorized as recommendations. They were increasing the resources at the data entry counter or introducing multiple data entry counters, eliminating temporary storing areas, and disaggregating the existing team into more empowered teams. However, the implementation of multiple data entry

counters with more ERP system logins incurs an additional expense for the company. This is because warehouse operations are considered non-value-added services, and management aims to minimize investment in functions associated with the warehouse. Given the constraints imposed by the budget and organizational resources, this particular study was undertaken for building and simulating basic models using Rockwell Arena software version 16. When analyzing the system, the study has utilized both animated and module-based development models to enhance the internal validity of the system as the outcomes are highly influenced by the parameters and limitations that are provided by the software.

III. Results

A. *Existing System*

The existing system had only one data entry counter, a team for carrying and storing greiges enabling the system to behave as an integration of single server queuing systems with the parameters of unlimited population size and limited waiting room capacity. The greiges are delivered to the warehouse and temporarily stored in a corridor. Subsequently, they are transferred to the warehouse door, though internal decisions may necessitate the return of certain greiges to the Quality Checking department. Upon their return, these greiges are temporarily stored again before undergoing the data entry process. The data entry process entails scanning details of each greige and attaching stickers with relevant information. Upon completion of this process, all greiges that have undergone data entry are transferred to a temporary location and stored until they are ready for use in the manufacturing process. It is important to note that the decision to immediately move some greiges into the rack is dependent on various factors. Proper storage of the greiges in the rack is a critical step in the manufacturing process and can significantly enhance their utility and effectiveness. Fig. 2 indicates the physical movement of greiges within the existing system.

Fig. 1. Animated model for the existing system

In summary, the exiting process includes the following steps that coincide with the observed variables:

i. Greiges arrival

ii. Deciding whether to return greiges to Quality Checking or forward them to the Warehouse

iii. Moving greiges to the data entry location

iv. Waiting for greiges to be scanned

v. Conducting the data entry process

vi. Moving the data-entered greiges to a temporary warehouse area

vii. Deciding which greiges should be moved to the rack first and which should wait where the system has analyzed assuming that the deciding criteria is FIFO

viii. Moving selected greiges near the rack using a forklift

ix. Storing the greiges in the rack.

The existing system had only one data entry counter, a team for carrying and storing greiges enabling the system to behave as an integration of single server queuing systems with the parameters of unlimited population size and limited waiting room capacity which is indicated by Fig 1.

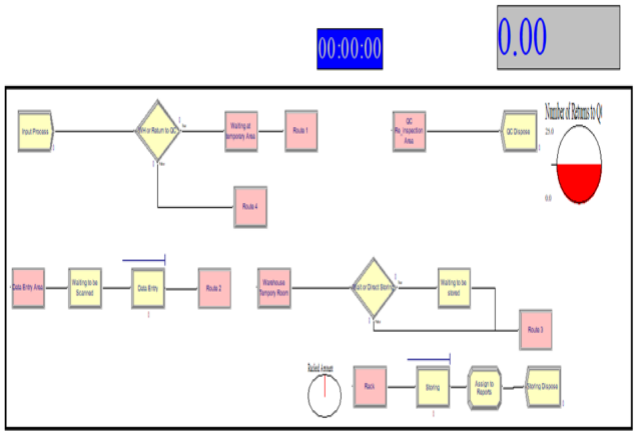

Fig. 2. Arena model for the existing system

The major issue with the existing is the higher amount of WIP indicating that the existing system has 93 WIP values indicating that 93*11 = 1023 greiges are still been processed which could result in increased honeycombing and losses of greige lots. More greiges are being waited at the data entry counter which is 24 lots of greiges and queue length at the storing process is 45 lots of greiges indicating that the system is inefficient. Data entry service provision time comprising of one person is 12 minutes per lot of greiges. To reduce WIP, the following models have been proposed under the basic three recommendation criteria.

B. *Proposed Models*

1) Proposed Models 01: Adding New Data Entry Counter

The study proposed to add a new data entry counter to the existing system as indicated in Fig. 3 to enhance the efficiency of the data entry process and to enhance the system efficiency. The new counter is expected to provide the same level of service as the current data entry machine. However, a financial analysis has determined that allocating another computer with an ERP system login would not be beneficial for the company. Thus, instead of implementing a completely new system, integrating the new data entry counter into the current system is recommended. This

approach would result in a reduction of costs while still achieving the desired increase in efficiency. In summary, the proposed model entails the addition of a new data entry counter with the same service provision rate as the current machine to the existing system. A financial analysis has determined that allocating another computer with an ERP system login would be financially inefficient; therefore, the study recommended integrating the new counter into the current system to reduce costs while enhancing efficiency.

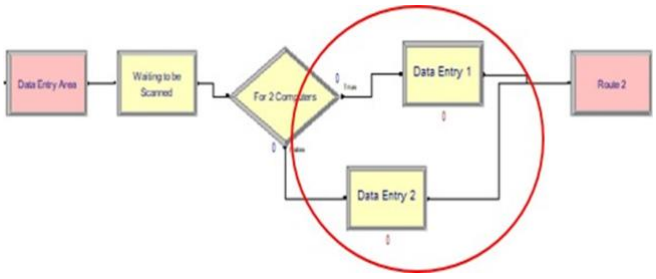

Fig. 3. Arena model with added new data entry counter

WIP has been reduced up to 61 lots of greiges where 61*11= 671 number of greiges are still been processed which still could result in increased honeycombing and losses of greige lots. More greiges are being waited at the two data entry counters which are 6 lots of greiges and 5 lots of greiges with the waiting times at each data entry counter being 1.51 and 1.38 minutes respectively. Meanwhile, queue length at the storing process has increased up to 49 lots of greiges compared to the existing system indicating that the system is inefficient. Data entry service provision time comprising of two persons with two ERP logins is 10.5 minutes per lot of greiges.

2) Proposed Model 02: Elimination of Temporary Storage of Greiges in the Warehouse Following the Data Entry

A new data entry counter is included in this proposed model, which processes data at the same rate as the existing data entry machine. It is determined, however, that allocating another computer with an ERP system login would not be financially beneficial to the company. Furthermore, the temporary storage of greiges in the warehouse following data entry is eliminated, and they are forwarded directly to the storing racks as indicated by Fig. 4. This eliminates the need for intermediate storage while also lowering the risk of errors and damage during the transfer of greiges from temporary storage to the storing racks. As a result, the new model simplifies data entry and improves operational efficiency.

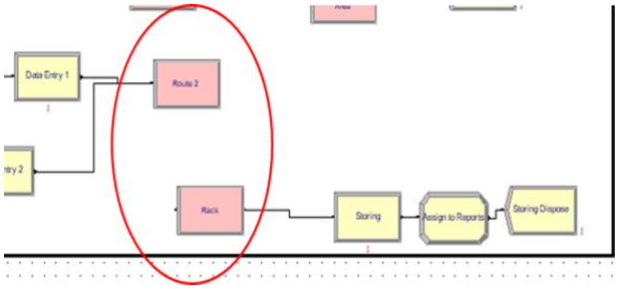

Fig. 4. Arena model with new data entry counter and eliminated temporary storage area

WIP has been reduced compared to the existing up to 79 lots of greiges where 79*11 = 869 number of greiges are still been processed which still could result in increased honeycombing and losses of greige lots. More greiges are being waited at the two data entry counters which are 7.56 lots of greiges and 6.44 lots of greiges with the waiting times at each data entry counter being 1.32 and 1.37 minutes respectively. Meanwhile, queue length at the storing process has increased up to 51 lots of greiges compared to the existing system indicating that the system is inefficient. Data entry service provision time comprising of two persons with two ERP logins is 4.48 minutes per a lot of greiges assuming that both employees in the data entry counter have the same working capabilities and same working conditions.

3) Proposed Models 03: Enhancing the Efficiency of the Data entry Process and Disaggregation of the existing team into separate teams without adding a new data entry counter to the existing system

The installation of a new data entry counter is not feasible due to financial limitations. It is planned to divide the current team of employees into two primary teams with more additional facilities such as two forklifts for each team for the job of storing greiges to reduce WIP as indicated by Fig. 5. and Fig. 6. Among defined recommendations, a model with all other three improvements except adding another data entry counter was the economically feasible model.

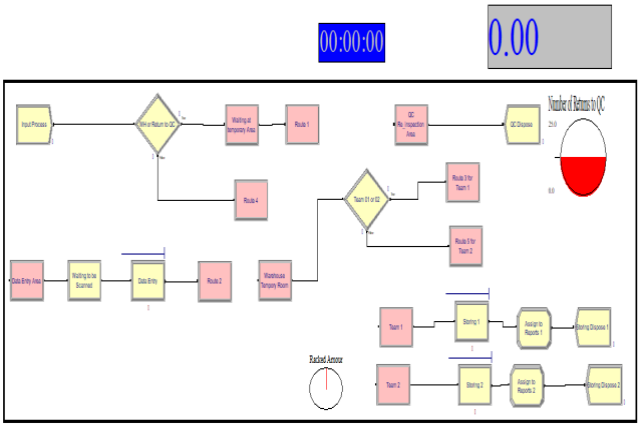

Fig. 5. Arena model with all recommendations except adding new data entry counter

Fig. 6. Indicates the animated view of proposed model 03 where the WIPs have been reduced and intermediate temporary storage areas which includes moving the data-entered greiges to a temporary warehouse area and deciding which greiges should be moved to the rack first and which should wait have been eliminated those results in less hair combing.

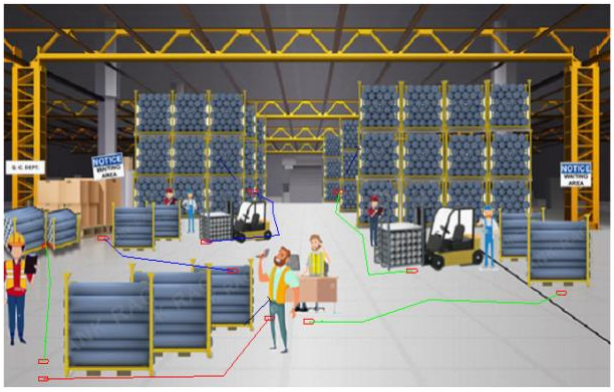

Fig. 6. Animated model with all recommendations except adding new data entry counter

WIP has been reduced compared to the existing up to 79 lots of greiges where 59*11 = 649 number of greiges are still been processed which still could result in increased honeycombing and losses of greige lots. Number of greige lots being waited at the data entry counter is 18 and queue length at the storing process has decreased to 31 lots of greiges compared to the existing system indicating that the system is an efficient system prioritizing the objective of reduced WIP. Data entry service provision time is 10.44 minutes per lot of greiges where this provision time is a lower value compared to the existing system.

Table 2 indicates the overall summary of each major performance indicator for the existing system and the proposed models obtained by simulation using Rockwell Arena software version 16 in order to logically compare the proposed alternatives for arriving at better solutions by utilizing a sample comprising 273 observations for each parameter.

TABLE II. COMPARISONS OF THE RESULTS OF THE EXISTING AND PROPOSED MODELS

Obtained parameter	Existing system	Proposed model 01	Proposed model 02	Proposed model 03
WIP (Lots of greiges)	93	61	79	59
Service time at data entry (mins)	12	10.61	4.48	10.44
Waiting time at data entry process (mins)	5.04	1.51	1.32	5.59
		1.38	1.37	
Waiting time at the storing (mins)	7.57	9.59	3.46	6.06
Queue length at data entry	24	6	7.56	18
		5	6.44	
Queue length at storing	45	49	51	31

When evaluating the proposed models against the performance parameters of the existing system based on several key performance metrics, each proposed model has demonstrated unique strengths and areas for further improvements leading to the selection of the best alternative among them contingent on specific operational goals and constraints. Proposed model 03 has demonstrated the lowest WIP, implying an efficient system of management. Enhanced throughput and reduced honeycombing which are advantageous for cost control as warehouse is a non-value-added function is indicated by reduced WIP. Proposed model 02 excelled in terms of service time at data entry, suggesting swift processing of greiges upon entry. This is beneficial for expediting the initial stages of workflow and the lowest waiting time at the storing process indicating efficient storage operations. Proposed model 01 showcased a substantially reduced waiting time at the data entry and the lowest queue length at the data entry. These enhanced parameters are crucial for minimizing delays at the data entry ensuring efficient utilization of resources. Subsequently, the choice among these proposed alternative models should align with the the objective of the study that reducing WIP and waiting times resulted in the proposed models 01 and 03 being slightly similar in terms of reduced WIP. However, a financial analysis from the company management which is not included in this research has determined that allocating another computer with an ERP system login would not be financially beneficial for the company.

IV. CONCLUSION

This study was undertaken to reduce work in progress and optimize the warehouse receiving process of a highly reputable fabric manufacturing company in Sri Lanka. It was identified that 93 lot of greiges work in progress and lengthy waiting queues were the major issues. Recommendations were defined under three possible improvements. They were increasing the resources at the data entry counter, eliminating temporary storing areas, and disaggregating the existing team into more empowered teams while providing more resources.

When considering the objective of reducing WIP proposed models 01 and 03 are slightly similar in terms of reduced WIP (59 – 61) and both options are better options for implementation. However, a financial analysis from the company management which is not included in this research has determined that allocating another computer with an ERP system login would not be financially beneficial for the company. Taking the financial feasibility into consideration proposed model 03 that has been recommended to enhance the efficiency of the data entry process and disaggregating the existing team into separate teams with additional facilities and empowered employees without adding a new data entry counter is the best alternative. This optimized model resulted in reducing work in progress up to 59 lots of greiges. Thus, eliminating temporary waiting areas and optimal use of the staff was the conclusion for reducing the work in progress. Since most of the fabric manufacturing companies are encountering a similar warehouse receiving process and storing procedures, the findings in this research are applicable to the fabric industry context in Sri Lanka.

The simulation with the limited edition has driven limited solutions such as limited simulation periods, limited number of input entries to the system, and limited programming and animation restrictions. The study can further be expanded toward improving the warehouse performance further minimizing the WIP and waiting times using five why analysis. Thus, the respective root causes can be identified and accordingly, the cause and effect analysis can be continued to find potential suggestions

Moreover, it is recommended that more observation of the activities occurring in this system is needed in future research. Therefore, it would be possible to determine the real situations with greater accuracy if it were possible to predict or calculate the likelihood of occurring and, at the same time, identify the best course of action for completely resolving any issues that may arise within the system. Future studies could optimize the rate of staff utilization and take into account not only waiting time but also the utilization rate for each counter. This research can be further investigated using options such as warehouse layout design towards storage facilities and business process reengineering. Additionally, it recommends conducting further longitudinal analysis and exploring further warehouse optimization techniques and feasibility analysis to obtain optimal results and refine the proposed strategies.

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2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

Strategic Analysis on Starbucks

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***Abstract*—This paper delves into a comprehensive strategic analysis of Starbucks, one of the world's leading coffeehouse chains. This paper analyzes Starbucks' strategic position through PESTEL and SWOT models, evaluates industry dynamics using Porter's Five Forces, and assesses core competencies with the VRIO model. The study aims to determine if Starbucks' current strategy is adaptable to future changes.**

Keywords—Starbucks, environmental analysis, SWOT, Strategic report, PESTEL, VRIO, Porter's Five Forces

I. Introduction

Starbucks established its' first outlet in Seattle in 1971 and has spread into many locations. In 1985, Starbucks began trading its' stocks on the NASDAQ (the American stock exchange). It is second to the NY Stock Exchange in the context of market capitalization of listed stocks [9], with more than 160,000 workers around the globe [18] Starbucks' mission statement "inspire and nurture the human spirit, one person, one cup, and one neighborhood at a time" hasn't changed for the last 30 years. Starbucks has expanded and It has over 30,000 locations in 78 regions with generating over $24 billion in revenue now. [1].

In America, 54% of the people (18+) consume coffee on a daily basis, and this entire community spends $40 billion averagely for the coffee. According to the statistics there is a huge potential demand and market for this product. Starbucks, with its competitors such as McCafé or Costa Coffee, have seized this opportunity and continue their development within this market [5].

Many people visit Starbucks daily not only for their cup of coffee, more than the costly coffee, these coffee consumers really like the polite and friendly Starbucks crew. Also, they believe that Starbucks is just more than coffee, it's symbol of love, trust and comfort [16].

II. Objective

As we delve into this strategic analysis of Starbucks, we will explore how the company's growth and enduring mission have shaped its strategic approach through using various models such as VRIO, SWOT, PESTEL and porters five forces. Additionally, we will examine the competitive landscape in the coffee industry and identifying the risks and threats faced by Starbucks and to evaluate its'' core competencies, seeking to understand if the company's strategies can maintain its position in a dynamic market. Also, this analysis aims to shed light on Starbucks' unique journey and its prospects for continued success in the evolving and challenging market while mitigating those risks and forecasting the future trends within the coffee industry.

III. Environmental Analysis

This section contains an analysis on the internal and external environment of Starbucks.

A. SWOT Analysis on Internal Environment

Being the Prominent leader in the market over the decades Starbucks has its own strength and opportunities in the market, however like other companies, it also faces some weaknesses and threats time to time.

Strengths

- Being the Leader in the Market

As of 2021, with 32,938 retail outlets, Starbucks is the largest coffeehouse enterprise internationally, it is well known. corporation that aims for superior quality in all their products. They give more concern to product quality and avoid quality homogenization, even if it evolves the larger production output [11]. As a result, Starbucks continues to be the industry leader.

- Rapid Expansion into the Market

Starbucks has a high growth rate, not only locally but also worldwide, is another strength. All the products from Starbucks are having constant or growing demand [5] Many of the new stores are from the foreign market. [16] They offer a diverse portfolio of products that attract people of all ages [3].

- Financially Strong

Starbucks is financially healthy and a strong company; this was proven by its performance during the 2008 and 2009 financial crises. Although its share price has dropped in the market, its profits have minimally dropped [16].

- Brand Awareness and Recognition

Starbucks' name recognition is one of its primary advantages. Starbucks is well known Company as a leader in the coffee and café market in the world due to its large exposure (30,000 locations) [18]. [1] Starbucks has considerable global exposure worldwide, with businesses in over 60 countries. Starbucks has been ranked as 91st among the top coffeehouse brands in 2013 around global. Starbucks effectively uses its strong brand value, awareness and strong market position by promoting products and franchising its trademark internationally.

- Loyal Customer Base

Starbucks has developed a great popularity among customers by utilizing its technology and innovations to

create a loyalty program that rewards frequent customers with free drinks [18]. With the Starbucks Rewards programs and the Starbucks Card, also they have commenced loyalty-based programs such as value cards program that offers convenience, supports donating, and encourages cardholders to visit stores more frequently and connected with their Starbucks mobile app [3].

- CSR Projects

Starbucks has always established itself as a socially responsible business. They have a strong social responsibility policy and use only ethically obtained products. [1] They are building and preserving their goodwill within their customer base through CSR Initiatives, and all their stores and outlets are ecofriendly, with a focus on proper waste management and trash reduction.

- Great Human Resource Management

Starbucks employees are highly smart, and they are recognized as the most valuable assets to the company and are often rewarded with excellent benefits such as stock options, retirement schemes, college financial support and a healthy work environment. [11] Excellent customer service is a result of Managing and supporting excellent human capital management. Fortune Magazine ranked Starbucks as 91st among the top 100 companies to work for.

- Warm & Friendly Outlets

Starbucks coffee stores are often found in key places, it can be spotted in lots of major locations such as office buildings, high traffic areas, near to the universities and campuses and suburban shopping spots. [5] This offers them quite access to reaching a mixed wide range customer base. Also, their outlets are nice and carry a warm vibe and they are designed to carry ‘cool’ factor. They also provide free Wi-Fi, wonderful music, and a pleasant environment for a friendly and community meeting spot. [16]. Having a perfect experience in Starbucks outlet is one of their major goals to turn their stores become. a "third place" in addition to home and work [11].

Weaknesses

- High Price

Starbucks' price is one of its significant weaknesses in their marketing initiatives, McDonald's utilizes Starbucks' high price against the firm. [16] the role of prices plays a major role when considering growth and expansion into other locations.

- Sole Product

Starbucks's' Another weakness is that its coffee beverages as well as other specialized drink products account for 75% of its income [18]. This means that Starbucks will face difficulty each time the price of coffee increases. [16] McDonald's and Dunkin Donuts are both making them less sensitive to rising coffee prices around the world by prioritize food above coffee, in their businesses [16]

- Too Many Locations in One Country

Starbucks has its outlets all around the world, but most of them are in the United States [25]. The corporation has crowded the market with over 14,000 outlets alone in US, and now its performance mainly based on the operations of the US stores. [1]

- In Adequacy of Capital

Another weakness is that around half of Starbucks locations are owned by the firm, while the other half are franchised locations [18]. This is a flaw because opening a corporate store requires more capital than opening a licensed store. This will limit development prospects [1].

- No Tailored Menu

Coffee culture in the United States and Europe are not same as in the other countries [11] and the corporation needs to adjust its menu and the interior outlet designs according to the local cultures and traditions [1] As part of its global expansion strategy, Starbucks' coffee customs may not be well embraced in other nations [11].

Opportunities

- Industrialization of the Countries

For Starbucks, the world market is the primary source of opportunities. In some of the countries with developing economies like the BRIC Countries, there are expanding upper and middle level income earners who desire to spend money on specialized and customized coffee. As those countries become more industrialized, their tastes are diversifying to include coffee. [16]

- Opportunity to Expand the Outlets

Starbucks has a great deal of potential to reach other markets as it expands into emerging and growing economies. This leads to an increase in their market share value by using their consistency, sustainability, expertise in the market, and financial strength. [11] This may reduce the negative impacts from the financial fluctuations in the UK. [1] The US market has been congested and statured therefore it’s very important to become globalized for businesses. Starbucks has already mounted a strong position in many countries. The recent partnership with India is good example for this [11].

- Technological Advances

Starbucks has partnered with Square for a mobile easy payment app which will lead the customer to make their payment through mobile phones, this will not create convenient and flexible to the customer also Starbucks has given some reward schemes through this app for the loyal customers, as technology creates lots of impact in businesses today A leader in the coffee industry like Starbucks knows how to seize the perfect opportunities by using the technologies to reach the maximum benefits [3].

- New Distribution Channels

Starbucks has introduced a beta version (prototype) like mobile apps for delivery. By implementing these strategic ideas Starbucks is expecting to leverage the opportunity to

increase distribution channels in order to reach more consumers in the future and ultimately which leads to increase their business with more customer base. [11].

- Expanding Product Mix and Offerings

Starbucks has recently begun to broaden their products' mix by introducing Tea, Fresh Juices and other beverages. This has led to more opportunities for Starbucks to create great prospects, they also introduced Starbucks capsules that can be easily prepared by their consumers at their home. This was created with the motive of giving their customer in store experience at their home [5].

Threats

- Highly Competitive

Specialty coffee is a highly competitive sector. Quality of the product, service, accessibility, and pricing are all elements that influence international market competition. For example, in the United States, it rivals with Dunkin Brands, which has a major presence in the North-eastern side of the US. Coffee and tea beverage products are offering through their channel development segment compete directly with teas & specialty coffees sold in supermarkets, clubs, and specialty stores in many overseas markets, it also faces competition from well-known competitors such as McDonald's. In many countries, McDonald's, that sells specialty coffee through their Mc Cafe stores, has an international presence and great brand recognition. because of this it could be a high threat to star bucks which has yet to establish its brand and presence in those markets. [11] Competitors such as Dunkin Donuts offer lower quality coffee compared to Starbucks, but their pricing is significantly lower. Starbucks may lose consumers if customer preferences change [1].

- Expensive Raw Materials/Non-Availability of Raw Materials

Increasing price of milk & Coffee is another greater threat to Starbucks. Fluctuation in the International Coffee Market will lead to a significant fluctuation for the market prices of high-quality coffee beans which cannot be controlled by Starbucks [11] The lack of inputs poses a serious threat to the company. Since the Coffee bean prices are subject to fluctuation, which has affected profitability at several instances in the past time. Starbucks simply cannot function without its coffee beans; thus, it has no choice but to pay whatever price is required for them. [1] Starbucks' main raw material is coffee beans, so price fluctuations in this resource could have an impact on the business operations. Whereas other factors such as natural catastrophes, weather conditions crop diseases could create the impact of the availability of the raw materials therefore these factors are indirect threats to the start bucks [11].

- Saturated Market

Starbucks receives a substantial portion of its revenue from developing markets, which are currently congested. [11, 5].

- Evolving Customer Tastes and Lifestyle Habits

The trend toward healthier products, as well as the possibility that coffee culture could become a fade, pose a challenge to Starbucks in the future [11].

- Effects COVID-19 Pandemic

The COVID-19 outbreak had a significant impact on purchasing habits, people's spending, and economic consequences all Restaurants Businesses were forced to function with significantly limited Customers or shut down completely, resulted a considerable hit in the revenue. Due to a coronavirus outbreak, Starbucks has temporarily closed over 2000 locations in China. In China, Starbucks has 4123 locations, almost half of them closed during the pandemic. [10] In 2020 financial year, total net revenues dropped 11% to $23.5 billion, down from $26.5 billion in the year 2019. In 2020, consolidated operating income declined to $1.6 billion, from $4.1 billion in 2019. The operational margin in fiscal 2020 was 6.6%, Decreased from 15.4% in 2019 Initially the Operating margin dragged down due to Sales deleverage and then additional costs increased as a result of COVID-19, such as enhanced pay and catastrophic pay programs and for outlet store partners, net benefits of state subsidies. The company's revenue per share (EPS) for fiscal 2020 dropped to $0.79 from $2.92 in fiscal 2019. COVID-19's negative effects were the primary cause of the drop [11].

Analyzing the Internal environment of Starbucks using SWOT analysis Company's high-quality products and strong customer connections through value-added services and operational networks are the primary strengths. However, the company's high dependence on the United States for main income and decline in the revenue has the direct influence in its financial stability. with the overall positive outlook for the international coffee market, US food service sector, increased Customer expenditure in the US, Starbucks likely to have more growth opportunities in broaden its geographical presence and increase the loyal customer base [11].

Summarized key points from SWOT analysis of Starbucks is given in the table below.

Table 1: Summary of SWOT Analysis

Strengths	Weaknesses
• Being the leader in the market. • Rapid expansion in to the market. • Brand awareness and customer base. • Warm and friendly outlets • Great human resources.	• High price • Sole product • High standard market (USA) • No tailored menu • In adequacy of capital
Opportunities	Threats

• Opportunities to expanding the outlets. • Brand extension • New distribution channels • Industrialization of the countries	• Expensive raw materials / non availability of raw materials highly competitive • Effects of COVID-19 pandemic • Decrease in consumer buying power

B. PESTEL Analysis on External Environment

Analyzing the external environment of Starbucks using PESTEL Analysis shows that Starbucks is a solid & stable corporation in the competitive market. This can be clearly seen since the demand for these products has never decreased in past years [13]. However, the recession and the Covid-19 pandemic posed a significant challenge to the entire business operations since it has the potential to alter customers' purchasing power. [15].

As a result, Starbucks should reconsider its price strategy, concentrate on providing reasonable products and to be more digitalized and technology friendly. They will be able to attract new clients and gain their trust in this manner [17].

A summary of the PESTEL analysis given below:

Table 2: Summary of the PESTEL analysis

Political	• Strict taxation policy and labour laws must be addressed to, particularly in the country from which they acquire their raw materials [17]. • High level of regulations implements by state in US (Home market) [13]. • Activism and increased political awareness in the supplier's countries [13].
Economic	• Operational cost and labor expansion of Starbucks. • Global economic downturn (2008) • Taxation levels, local currency exchange rates, and the constrained economic climate [17].
Social	• Income distribution and level of people [13]. • Market participants who are well-educated [17]. • Changing consumer preferences [17].
Technological	• Wi-Fi is available in all of the company's locations [18]. • Starbucks also introduce mobile apps for payments [13]. • Partnering with Apple to support an app-based discounts with vouchers through the mobile apps [13].
Environmental	• Starbucks must follow CSR projects based on Re-Cycle, Re-Use, Re-Invent processes [13]. • Criticism and pressure among worldwide activists and advocacy groups [17]. • Natural hazards in places where coffee beans are grown. And COVID-19 Pandemic [13].
Legal	• Health regulations related foods must be followed. • Industry related specific licensing regulations. • Implementation of caffeine manufacturing and use policies [13].

C. Analysis of the Competitive Environment by Porter's Five Forces Model

Analysis on Porter's five forces model for Starbucks is given below:

Table 3: Porter's five forces

Barriers for the new entrants	Moderate Level	Heavy competition among the existing companies and difficulties accessing the raw materials as the well establish companies like Starbucks. [19]
	Moderate to high	COVID-19 outbreak may have an impact on consumer behavior and customer traffic, resulting in temporary changes in business's seasonal fluctuations. [18]
Bargaining	Moderately Low	As a result of the fair-trade policy of Starbucks and the wide range of loyalty customer base over the years. [19] whereas after the COVID–19
	High	Decrease in demand for coffee products because of the pandemic, health measures, store closures, quarantined changes in customer

power of both suppliers and buyers		expenditure behaviors. [18] Suppliers maybe adversely effected by the pandemic due to lack of sufficient financial assistance as well as meeting the requirements in terms of supplying goods, due to social, political economic, or labour instability, reduced working hours, transportation interruptions, health-safety measurements, and travel restrictions. [18]
Threat of alternatives, and substitute	High	Every coffee shop, is attempting to be more unique and specialize in coffee substitute products are the greatest concern is in the market [19]
	High	Because of Covid-19 there is a reduction in consumer demand for premium coffee products including customer preferences for other goods as well declining demand for products [18].
Competitive rivalry	High	There is not any cost incurred by the buyers to switch to a competitor, this resulting in intense competition in the industry. [3]
	High	Existing market competition without any changes

D. Analysis of Core Competencies-Based VRIO Model

VRIO analysis stands for Value, Rarity, Imitability, and Organization. It identifies the strengths of the company and its most essential internal resources followed by their significance to achieve competitive advantage.

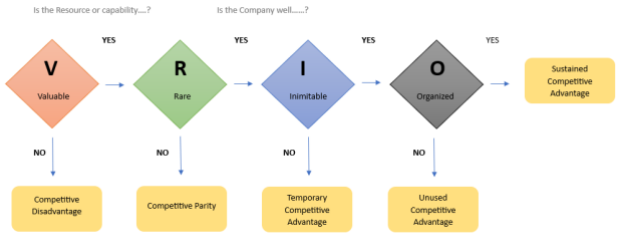

Fig. 1: Flow chart of VRIO model

Table 4: VRIO Analysis on Starbucks

Resources	Value	Rarity	Imitability	Organization	Competitive advantage
Customer base	Yes, the company has made investments to cultivate strong customer loyalty	yes	Competitors are trying Imitate but none of them succeeded so far	Using really well so far	Medium term of advantage
Brand recognition	Yes	Yes Leading Brand in the industry	No	Used well to Stable its leading position in the market	Long term advantage
Financial Resources	yes	No	Resources are available for all Companies	Solid and safe Financial Position	Temporary
Human capital	yes	No	Can imitate by Competitors	Yes, the company successfully sustained them over the years.	Temporary
Sales force	Yes	No	Can imitate	Still Have room for Lot of potential	Potential Sustainable competitive advantage
Product portfolio	Yes, its valuable because, its consumers preference	The majority of competitors are attempting to enter profitable segments.	High chance of Imitability	Yes used them Successfully	Provides a temporary competitive advantage, but needs continuous innovation to maintain.
Suppliers	Yes	Yes	Competitors can start sharing some suppliers as well.	Fully used	Main reason for the Business Continuity
Intellectual rights & Copyrights	Yes, Extremely Valuable	Yes , Cant copy	Risk of Imitation,	Not fully used	Gives strong Competitive Advantage

Global reputation and human resources are a prominent and valuable aspect. However, it does not provide Starbucks with a competitive edge in the long-term as it is not expensive to imitate, although human capital can provide a company. With a great competitive advantage this is only temporary until other company starts to imitate it [19].

Customers would love to visit a coffee shop with creative decor; therefore, the store's appeal is also valuable. however, since other coffee shops may simply imitate it so it's not a rare resource. As a result, this aspect offers Starbucks with competitive rivalry.

Starbucks's primary strength is its brand recognition and awareness. It is impossible to attain by imitation. To gain brand recognition, a firm must take a lot of observations and measurements whereas Starbucks maintains brand recognition over the years now that gives the company a long-term competitive edge [19].

Starbucks is well-known for its dedicated customers. Its buyers are quality-conscious, and they are not bothered with it. High pricing continues to receive excellent customer service and the quality product which is unique and impossible to duplicate. It's hard to gain someone's loyalty. As a result, this component aids the organization in gaining a long-term competitive edge [19].

E. Key Industry Developments from the Environment Analysis

E-Commerce platforms and Digitalization

Starbucks's second biggest, fast-growing market with an advanced digital eco system is "China". They are putting on this ecommerce much earlier in the market process than in the U.S, and they have collaborated with some major companies like WeChat and Alibaba [23] and Starbucks recently engaged digitalized the paying method by introducing the 'Mobile Go and Pay', Starbucks can identify the consumer behavior, that will have an impact on the sales [7].

Customized Menu with healthier products:

After COVID pandemic People starts to care more about their health in terms of eating patterns, safety measures and lifestyle, this change among the people leads whole coffee

industry to think more of healthy products, therefore Starbucks added plant-based items and innovative cold beverages such as cold foams and nitro cold brew in their menus [18].

More Customized outlets:

Starbucks has been recovering to go back to its solid position after pandemic, the improved infrastructures are one of the main reasons for this. for example, in last 3 months 80% of the visitors came via the drive-through which was not the case previously, this and other delivery methods have driven them much higher on the recovery curve. Therefore, Starbucks should make partnership or create different delivery methods to the customer's home or offices [22].

Forming New Collaborations:

Food sales currently shows 20% of Starbucks' income have been steadily increasing. To fully capitalize on the growing popularity of its complementing coffee and food menus, Starbucks is forming partnerships and has declared its plans to enter the brunch market. Hence, Starbucks anticipates that food sales will generate 25% of the income during the next five years [22].

IV. Strategic Position and Value Proposition of Starbucks

A. Strategic Position

Starbucks has established itself as a well-established firm with high brand recognition and positioned themselves in a way that its products can be distinct from its competitors, that gives them competitive advantage. The main strategic evaluation criteria are growth, expansion, profitability, customer satisfaction and market share [14].

Net promoter score, which is used to evaluate consumer satisfaction, Starbucks has scored 77 in that, [24]. Starbucks' score places the corporation in a very high position across all companies, with a maximum net promoter score of 100. It showed a great level of customer satisfaction. [1]

B. Value Proposition

The following are the three primary components of their value proposition.

1. Premium Quality

Starbucks offers the highest-quality coffee in the world, which is mostly controlled by their supply chain and these raw materials are from Central America, Africa, and Asian pacific regions. Starbucks directly works with farmers and purchase green coffee beans, and it supervises the tailored roasting method, and it monitors distribution to retail stores worldwide. [12]

2. Customer-Intimacy

Mr. Alling who is the senior vice president (North American retail) said that "Our goal is to create an uplifting experience every time you walk through our doors". E.g. - Customers have freedom to choose the type of beverage they wish, not just coffee. [12] Staffs were supposed to remember all their regular clients' names as well as their preferences.

3. Atmosphere

Starbucks is famous for providing excellent customer service and a memorable in-store experience [5]

V. Risks Invloved Within the Industry

A. Competition

Intense competition within the industry is a significant risk. New entrants and existing competitors in the coffee industry will offer various substitute and diverse range of products might challenge Starbuck market value and share. Competitors may attract consumers with low price alternatives or innovative products, these strategies can cause a great impact in the customer base, profitability, and revenue of Starbucks. [1]

B. Market Abundance and Saturation

Starbucks faces the risk of market saturation, especially in the US with a large number of coffee outlets and stores. Over saturation can greatly affect store efficiency and reduce the sales, and slower the growth opportunities. It can reduce profits in the new store openings and potential store closures. [11]

C. Disruptions in the Supply Chain

Another great risk is Supply chain disruptions for Starbucks, especially items of the main raw material the coffee bean purchases. [1] Fluctuations in coffee bean prices due to external factors such as climate changes or weather conditions or trade restrictions can have significant effect in production and supply costs and revenue. [5] Also the disruptions or shortages in the supply chain will affect the quality and production efficiency and availability.

VI. Future Trends

A. Digital Transformation

Continued emphasis on digital innovation is important to Starbucks. This includes increasing mobile ordering capabilities, personalized experiences through apps, loyalty programs, and using technology to streamline operations and improve customer engagement.

B. Risk Mitigation Strategies

Developing robust risk mitigation strategies is imperative. This includes supply chain resilience measures, proactive competition analysis, customer-centric initiatives, and scenario planning to navigate uncertainties like pandemics or market fluctuations.

C. Consumer Centric Innovation

Prioritizing customer-centric innovation by focusing on consumer preferences, convenience, and experience enhancement through technology, product innovation, and service improvements is critical for sustained success.

D. Health & Wellness Focus

The rising trend of health-conscious consumers presents opportunities for Starbucks to expand its offerings with healthier menu options, plant-based alternatives, and functional beverages. Embracing wellness trends aligns with changing consumer preferences.

VII. Conclusion

Starbucks is adopting a firm position in the industry and achieving promising strategic and operational goals. Starbucks is a successful business structure that should be followed by other companies. Starbucks should stick to its core talents and capabilities, transferring them worldwide with caution and in accordance with local culture and norms.

Starbucks is financially stable and safe and can afford to invest in new stores both locally and internationally which would help to increase market share and brand popularity. Starbucks has proven that its strategy has worked well in terms of profit and consumer engagement as it should remain to its existing strategy. Starbucks should be more concern with higher quality of their products since the aggressive expansion Could affect this.

VIII. Recommendations

- Many organizations are still trying to re-evaluate their current strategies and reinvent their business theories and models after a post-COVID-19, because of the global epidemic, likewise, Starbucks enterprise should also predict and foreseen the trends or threats which affects the coffee industry and strategically leverage and identify these opportunities and be a market leader [2].
- It should also look at potential local locations for the drive-through store formats, with major urban cities like New York, L.A., Chicago, and Atlanta [1].
- Given the growing rivalry in the industry, it is recommended that Starbucks invest more in advertising and branding initiatives and use a variety of promotional platforms such as commercials, Branding, social media etc. To represent unity, strength, and consistency [2].
- Since the world is recovering Slowly from COVID-19 Starbucks Should be aware of fluctuations in culture, economy, and government in order to anticipate the issues clearly and to mitigate the risks very well [18].

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2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

Growth, Instability, and Competitiveness of Sri Lankan Tea Exports

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***Abstract*—Sri Lankan tea exports have significant impact on world tea exports as well as the country's economy. Although Sri Lanka is one of the leading tea-producing and exporting nations in the world, the percentage share of Sri Lankan tea, also renounced as Ceylon Tea in the global tea market has gradually decreased over the years. With this background, this study aims to comprehensively investigate the growth patterns, instability, competitiveness, and future prospects of tea exports, and propose recommendations to improve the tea export industry in Sri Lanka. Secondary data were sole source used in this study. The Compound Annual Growth Rate Analysis was employed to measure growth rates in production and exports of Sri Lankan tea, while instability in production and export indicators of tea in Sri Lanka was calculated by using the Cuddy Della Valle Instability Index. Further, a matrix association between growth rate and instability index was employed to classify the major tea importing destinations into four categories. Revealed Comparative Advantage Indices were employed to measure export competitiveness of Sri Lankan tea. Sri Lankan tea export quantity has shown negative growth, while tea export value has depicted positive growth during the period from 2011 to 2022. Tea exports, irrespective of the process, have shown low instability during the study period. At the same time, Iraq was the most stable market for Sri Lankan tea exports. According to the Revealed Comparative Advantage index results, Sri Lanka has shown very strong export competitiveness in the world tea market.**

Keywords—Compound annual growth rate, competitiveness, cuddy della valle instability index, tea exports

I. INTRODUCTION

Tea is considered one of the key agricultural export commodities in Sri Lanka and it plays a vital role in the economy as well as the socio-cultural scenario of the country over the centuries. In 2021, tea exports as a percentage of total exports were about 11 per cent while it was 38 per cent of the total agricultural exports in Sri Lanka [1]. Sri Lanka is the 4th leading tea manufacturer and 3rd biggest tea exporter in worldwide [1]. Therefore, Sri Lankan tea exports had a tremendous impact on global tea export market as well as the country's economy. Even though the word "Ceylon" has become tantamount of the world's finest tea in over one hundred and fifty years, the percentage share of Sri Lankan tea in the world market has significantly decreased continuously [2]. Therefore, presently the Sri Lanka experienced the mislaid of its top position in the world tea market and many of its traditional country markets[3]. The Sri Lankan tea industry should be competitive among the other tea producing and exporting countries and maintain stability in the marketplace to acquire economic benefits to the country. According to existing literature, there are some scientific evidence available in terms of the export trend in the global tea trade [4]. However, there are no recent studies available in this regard and no study has been made on the instability of tea exports over the years. According to existing literature there is no study can be found on the use of Revealed Comparative Advantage indices especially Revealed Symmetric Comparative Advantage (RSCA), Trade Balance Index (TBI) and product mapping to assess the export competitiveness of Sri Lankan tea internationally. With this background this study was aimed to examine the historical growth patterns and instances of instability in the domain of Sri Lankan tea exports. Further, the study examined the competitiveness of Sri Lankan tea exports among other leading tea exporting nations.

II. METHODOLOGY

This study solely depends on secondary data. The overall study period was 2011 to 2022. Tea export data (from 2011 to 2022) collected from the Sri Lanka Tea Board were used. World tea exports and imports in terms of total and country-wise were gathered from the International Trade Centre (ITC) Trade Map. Further, total merchandise exports data for the period of 2011 to 2022 in terms of World and major tea exporting nations were gathered from World Development Indicators (WDI).

A. Compound Annual Growth Rate Analysis (CAGR)

The growth rates of production and export indicators for Sri Lankan tea arrived by using the exponential type of compound growth function as follows [5].

$$Y = ab^t e_t \qquad (1)$$

Where, Y = Dependent variable for which growth rate is to be estimated (Production (Mn kg) /Extent (ha) /Quantity exported (Mn kg)/ Total real export earnings (Rs. Bn))

a = Intercept
b = Regression Coefficient = (1+g), where g is the compound growth rate
t =Time variable (Years which takes values, 1, 2, …, n)
e_t = Error term

The logarithmic form of the equation (1) as follows:

$$Log\ Y = \log a + t \log b + \log e_t \qquad (2)$$

The compound growth rate (g) in per cent will be calculated by using the following association.

$$g = (\text{antilog of } (\log b)\text{-}1) \times 100 \quad (3)$$

The significance of the coefficient was tested using the t statistics.

B. Instability Analysis

Co-efficient of variation (CV) and Cuddy Della Valle Index (CDVI) [6] was used to measure the instability in both production and export indicators of Sri Lanka tea for the period 2011 to 2022.

1) Co-efficient of Variation (CV)

Co-efficient of Variation which was the simplest measure of instability which can be estimated as follows.

$$CV = (\text{Standard deviation/Mean}) * 100 \quad (4)$$

2) Cuddy Della Valle Instability Index (CDVI)

In this study, CDVI was employed to assess the instability in Sri Lankan tea exports as well as production indicators. The Cuddy-Della Valle Index can be expressed as follows.

$$CDVI = CV * \left(\sqrt{1 - \bar{R}^2}\right) \quad (5)$$

3) Matrix Association between Growth Rate and Instability

Matrix association between growth rate and instability index was employed to classify the importing countries into four categories [7] as follows.

1) **High Growth and Low Instability (Highly Preferable):** A nation whose compound growth rate is greater than the average, but the instability is lower than the average value.

2) **High Growth and High Instability (This category is preferable based on the greatness of growth over instability index):** A nation whose compound growth rate and instability are greater than the average.

3) **Low Growth and Low Instability (Less Preferable):** A nation whose compound growth rate and instability index values are lesser than the average.

4) **Low Growth and High Instability (Not Preferable):** A nation whose compound growth rate is lesser than the average, and whose instability value is greater than the average.

C. Export Competitiveness Indices

In this study, export competitiveness of Sri Lankan tea was examined using various measures. Further, export competitiveness of other leading tea exporters was also calculated with an intention of comparing Sri Lankan export performance with its competitors.

1) Revealed Comparative Advantage (RCA)

In this study, standard Balassa's Index and its various modified measures were applied to measure the competitiveness of Sri Lankan tea exports in global market. Standard Balassa Index (RCA_{ij}) can be exhibited as follows.

$$RCA_{ij} = (X_{ij}/X_i)/(X_{wj}/X_w) \quad (6)$$

Where, X_{ij} represents the export value of the j^{th} product in the i^{th} country; X_i represents the total merchandise exports of i^{th} country; X_{wj} represents the total export value of the j^{th} product in the world; and X_w represents the total merchandise exports of world. Generally, the RCA > 1 means the country is really taking the advantage of exporting the commodity i.

RCA index ranges of the export competitiveness of agricultural commodities as follows; RCA $\geq$ 2.500 – Very strong export competitiveness, 1.250 = RCA < 2.500 – Strong export competitiveness, 0.800 = RCA < 1.250 – Medium export competitiveness, and RCA < 0.800 – Weak export competitiveness [8].

2) Revealed Symmetric Comparative Advantage (RSCA)

The Revealed Symmetric Comparative Advantage (RSCA) index was proposed by Dalum et al., [9] and Widodo [10]. Revealed Symmetric Comparative Advantage (RSCA) index expressed as follows.

$$RSCA = (B\text{-}1) / (B+1) \quad (7)$$

Where B is original Balassa's revealed comparative advantage index and values of RSCA range in +1 and -1 with zero as neutral point with respect to comparative advantage.

3) Trade Balance Index (TBI)

Trade Balance Index (TBI) which was proposed by Lafay [11] was employed to analyze whether a country is a net exporter or net importer of tea. TBI can be expressed as follows.

$$TBI_{ij} = (X_{ij}\text{-}M_{ij})/(X_{ij}+M_{ij}) \quad (8)$$

Where Xij and Mij represent the exports and imports of commodity j by country i. TBI index value ranges from -1 to +1. If TBI equals to the -1, country only imports. If TBI equals to the +1, country only exports. If any value is within the range of -1 to +1, the country exports and imports a commodity simultaneously.

4) Product Mapping

Product mapping can be obtained by combining both values of RSCA and TBI Indexes.

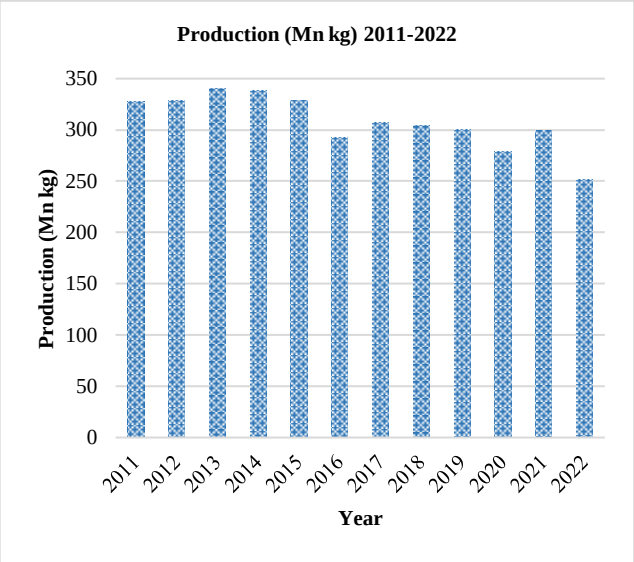
	Net Importer	**Net Exporter**
RSCA >0	**Group B** Have Comparative Advantage, No Export Specialization (net importer) (RSCA>0 and TBI <0)	**Group A** Have Comparative Advantage, Have Export Specialization (net exporter) (RSCA>0 and TBI>0)
RSCA < 0	**Group D** Have Comparative Disadvantage, No Export Specialization (net importer) (RSCA <0 and TBI<0)	**Group C** Have Comparative Disadvantage, Have Export Specialization (net exporter) (RSCA < 0 and TBI >0)
	TBI < 0	**TBI > 0**

Source: Widodo, (2008) [10]

III. RESULTS

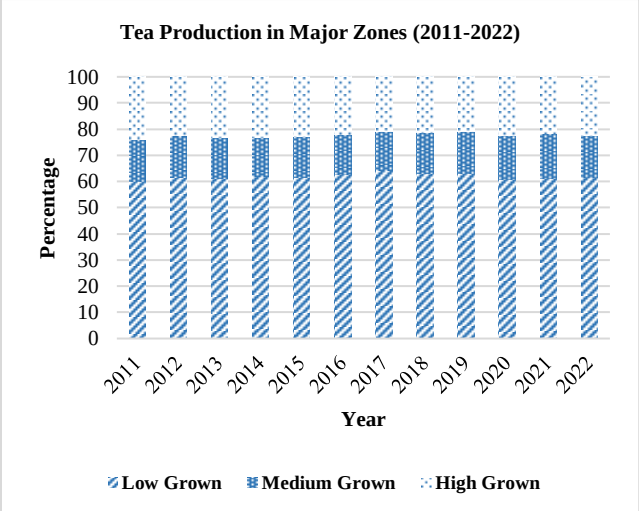
A. Production Patterns of Sri Lankan Tea

The tea production of Sri Lanka showed a negative trend throughout the selected study period (2011-2022). The highest tea production can be seen in the year 2013, due to favourable climatic conditions in all tea growing areas [12]. The lowest tea production can be seen in 2022 due to an inadequate supply of chemical fertilizers [13].



Source: Authors' Compilation Based on Sri Lanka Tea Board Statistics (2023)

Fig. 1. Tea production trends (2011-2022)



Source: Authors' Compilation Based on Sri Lanka Tea Board Statistics (2023)

Fig. 2. Tea production in major zones (2011-2022)

The terms "up-country," "mid-country," and "low-country" can be used to describe three main tea-producing regions in Sri Lanka. The low-country tea shows over 60 per cent of the contribution to Sri Lanka's total tea production through the period from 2011 to 2022 (see. Fig. 2). High-country, mid-country and low-country tea are popular in different niche markets worldwide due to their distinctive tastes and other specialties. For example, as stated in [1], Uva teas from up country are popular in Germany and Japan. Medium-country tea is popular in countries such as Australia, Europe, Japan and North America due to its unique thick colour. Further, there is a huge demand for Sri Lankan low-country teas from Western Asia, the Middle East, CIS, and BRICS countries.

B. Compound Annual Growth Rates for Production Indicators of Sri Lankan Tea

The results in Tab. 1 revealed that tea extent shown a positive growth rate while production shown a negative and significant growth rate through the period from 2011 to 2022 irrespective of the elevation type. However, the total production of Crush, Tear, and Curl tea (CTC tea) has shown positive growth while orthodox and green tea production in the country has shown negative growth rates throughout the study period.

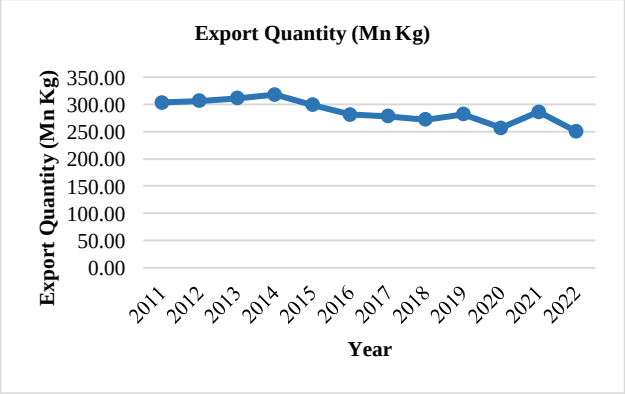
TABLE 1: COMPOUND ANNUAL GROWTH RATES FOR PRODUCTION INDICATORS OF TEA (2011-2022)

Indicator	Compound Growth Rate (% per annum)
Extent (ha)	0.81^{NS} (0.009)
Production (Mn kg)	-1.58* (0.004)
Production According to Elevation	
High Grown (Mn kg)	-2.74* (0.005)
Medium Grown (Mn kg)	-2.06* (0.004)
Low Grown (Mn kg)	-1.38* (0.004)
Production According to Process	
Orthodox (Mn kg)	-1.85* (0.004)
CTC (Mn kg)	1.00^{NS} (0.006)
Green Tea (Mn kg)	-4.31* (0.01)

Note: Figures in parentheses shown standard errors for their respective coefficients, * indicates coefficients are significant at 5 per cent, NS represents not significant

Source: Authors' Work Based on Sri Lanka Tea Board Statistics (2023)

C. Growth Patterns in Sri Lankan Tea Exports

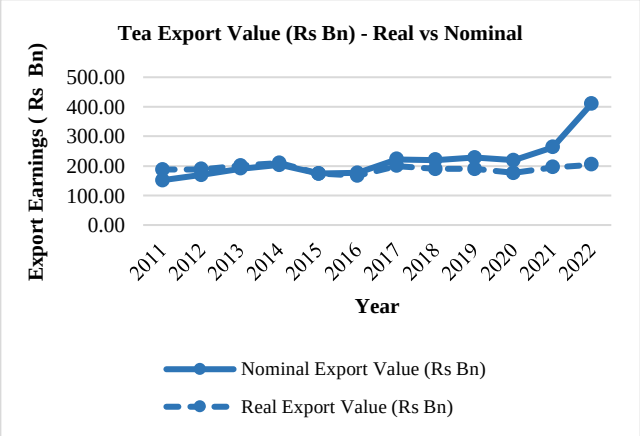


Source: Authors' Compilation Based on Sri Lanka Tea Board Statistics (2023)

Fig. 3. Total tea exports quantity (2011-2022)

From 2011 to 2022, the tea export quantity shows a downward trend while tea export value has an upward trend. The highest tea export quantity can be seen during 2014 and this may be owing to the crowning tea production quantities in the preceding year (see. Fig. 1). The lowest tea export quantity can be seen in 2022 throughout the study period

owing to the lowest tea production in year 2022. However, the highest value in tea export earnings in nominal terms can be seen in 2022 and this may be due to the rupee devaluation during the same year (see Fig. 4). As depicted in Fig. 4, the total tea export earnings in terms of both nominal and real values shows an upward trend throughout the study period (2011-2022).



Note: For real value - GDP Deflator, base year = 2015
Source: Authors' Compilation Based on Sri Lanka Tea Board Statistics (2023) and World Bank Data (2023)

Fig. 4. Total tea exports value (2011-2022)

D. Growth Rates and Instability of Sri Lankan Tea Exports

The secondary data on annual tea exports of Sri Lanka with respect to both quantity and value from 2011 to 2022 were used for this analysis.

TABLE 2: COMPOUND ANNUAL GROWTH RATES AND INSTABILITY OF TEA EXPORTS FROM SRI LANKA (2011-2022)

Indicator	Process	Compound Growth Rate (% per annum)	Instability (CDVI)
Export Quantity	Black Tea	-2.11* (0.003)	3.61
	Green Tea	-1.89* (0.005)	6.34
	Instant Tea	5.72* (0.008)	9.47
Export Value	Black Tea	0.55^{NS} (0.005)	6.48
	Green Tea	1.44^{NS} (0.007)	8.86
	Instant Tea	7.63* (0.01)	11.04

Note: Figures in parentheses shown standard errors for their respective coefficients, * indicates coefficients are significant at 5 per cent, NS represents not significant
Source: Authors' Work based on SLTB Data (2023)

According to Tab. 2, Instant tea exports have shown significant and positive growth rates with regard to both volume and earnings. Consequently, black tea and green tea exports have exposed adverse growth rates in terms of quantity while it shown positive growth rates in terms of value. Tea exports have shown low instability in terms of both quantity and earnings irrespective of the process type.

TABLE 3: COMPOUND GROWTH RATES AND INSTABILITY OF CATEGORY-WISE SRI LANKAN TEA EXPORTS FOR THE PERIOD OF 2011-2022

Indicator	Category	Compound Growth Rate (% per annum)	Instability (CDVI)
Export Quantity	Bags	-1.51* (0.006)	6.83
	Bulk	-0.95* (0.001)	1.19
	Packets (>3kg)	5.82* (0.008)	9.38
	Packets (1kg-3kg)	1.86^{NS} (0.035)	36.60
	Packets (3Kg-5kg)	-1.63^{NS} (0.01)	12.67
	Packets (4g-1kg)	-.3.04* (0.004)	4.66
	Packets (5kg-10kg)	-3.23* (0.008)	9.53
Export Earnings	Bags	-0.12^{NS} (0.007)	7.83
	Bulk	0.32^{NS} (0.005)	6.38
	Packets (>3kg)	7.85* (0.01)	11.20
	Packets (1kg-3kg)	1.07^{NS} (0.035)	37.50
	Packets (3kg-5kg)	-0.54^{NS} (0.011)	12.60
	Packets (4g-1kg)	-1.06^{NS} (0.007)	8.45
	Packets (5kg-10kg)	-2.65* (0.008)	9.21

Note: Figures in parentheses shown standard errors, * indicates significance at 5 per cent, NS represents not significant; (0-15 = low instability, 15- 30= medium instability and 30 & above = high instability)
Source: Authors' Work based on SLTB Data

Out of different product categories, exports of tea packets (> 3kg) showed the maximum value of growth rates among other categories in terms of both export volume and earnings throughout the study period (2011 -2022). All categories except exports of tea packets (>3kg) and packets (1kg- 3kg) showed negative growth rates in terms of export quantity. Tea in bulk, packets (>3kg), and packets (1kg-3kg) showed positive growth rates in export value. Exports of tea packets (1kg- 3kg) showed high instability in terms of both quantity and value while other categories showed low instability (see. Tab. 3).

E. Results of the Instability Index and Compound Growth Rates by Import Destination

This section focuses on major importers of Sri Lankan tea exports. During the years 2001 to 2023, these nominated importers were ranked among the top ten. Major importing nations of Sri Lankan Tea were Russia, Iran, Iraq, UAE, Turkey, Azerbaijan, and others (Tab. 4). All major import destinations and others except Iraq and Turkey indicated negative growth rate in terms of export quantity. Iraq exhibited the highest growth rate of 6.40 per cent and 6.93 per cent in terms of export quantity and values respectively. Russia and Iran shown negative growth rates in tea export earnings. Moreover, total tea exports from Sri Lanka were negatively growing in terms of volume while positively growing in terms of earnings from 2011 to 2022.

TABLE 4: DESTINATION-WISE GROWTH RATES FOR TOTAL TEA EXPORTS FROM SRI LANKA (2011-2022)

Country	Compound Growth rate (% per annum)	
	Export Quantity	Export Value
Russia	-6.66* (0.004)	-5.78* (0.01)
Iran	-10.67* (0.011)	-7.84* (0.01)
Iraq	6.40* (0.007)	6.93* (0.008)
UAE	-1.73^{NS} (0.031)	0.01^{NS} (0.034)
Turkey	5.05* (0.017)	5.71^{NS} (0.026)

Azerbaijan	-0.09^{NS} (0.005)	1.07^{NS} (0.01)
Other	-2.16* (0.004)	0.47^{NS} (0.003)
Total	-2.05* (0.003)	0.11^{NS} (0.006)

Note: Figures in parentheses shown standard errors for their respective coefficients, * indicates coefficients are significant at 5 per cent, NS represents not significant

Source: Authors' Calculation Based on Sri Lanka Tea Board Statistics (2023)

F. Instability Results: Destination-Wise Analysis

The results of the CDVI with the CV of Sri Lankan tea exports for different export indicators are presented in Tab. 5. According to CDVI values, other countries showed the lowest instability in quantity (5.28%) and value (6.13%) of tea exports in Sri Lanka. During the study period (2011-2022) all importing destinations exhibited instability in tea exports from Sri Lanka in terms of different export indicators. Of major importing countries Iraq is the most stable market for Sri Lankan tea exports in terms of volume (5.62%) and earnings (9.46%). Further, UAE (32.22%) was the most unsteady market in terms of tea quantity exported from Sri Lanka during 2011 to 2022 while Turkey (30.77%) was the most unsteady market in terms of tea export earnings.

TABLE 5: DESTINATION-WISE INSTABILITY ANALYSIS OF SRI LANKAN TEA EXPORTS (2011-2022)

Destination	**Export Quantity**		**Export Value**	
	CV (%)	**CDVI (%)**	**CV (%)**	**CDVI (%)**
Russia	26.02	6.90	25.25	12.62
Iran	34.23	9.63	30.23	14.40
Iraq	23.13	5.62	25.12	9.46
UAE	32.22	32.22	26.29	11.84
Turkey	27.87	14.65	30.77	30.77
Azerbaijan	6.40	6.40	16.42	16.19
Other	9.38	5.28	6.29	6.13
Total	8.13	3.61	6.75	6.75

Source: Authors' Calculation Based on Sri Lanka Tea Board Statistics (2023)

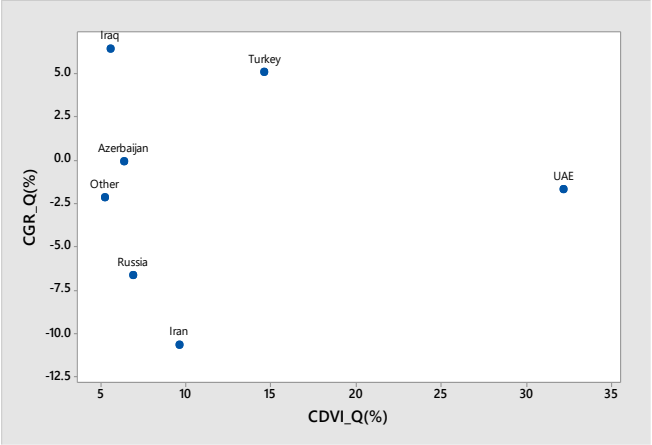
Import destinations for Sri Lankan tea exports were classified into four categories depend on the results of growth rate analysis and instability index [6]. The average value of the compound growth rate of export quantity is -1.41 per cent while the growth rate of export earnings is 0.88 per cent. If the compound growth rate is larger than the calculated average value it illustrates high growth and fewer than the average value it exhibits low growth. The average instability index values of export volume and export earnings are 11.53 and 14.49 per cent respectively (Tab. 6). If the CDVI instability index value is superior than the average value it shows high instability and fewer than the average value it shows low instability.

TABLE 6: DESTINATION-WISE GROWTH RATE AND INSTABILITY INDEX

Country	**Compound Growth Rate (% per annum)**		**CDVI (%)**	
	Export Volume	**Export Earnings**	**Export Volume**	**Export Earnings**
Russia	-6.66	-5.78	6.90	12.62
Iran	-10.67	-7.84	9.63	14.40
Iraq	6.40	6.93	5.62	9.46
UAE	-1.73	0.01	32.22	11.84
Turkey	5.05	5.71	14.65	30.77
Azerbaijan	-0.09	1.07	6.40	16.19
Other	-2.16	0.47	5.28	6.13
Average	**-1.41**	**0.08**	**11.53**	**14.49**

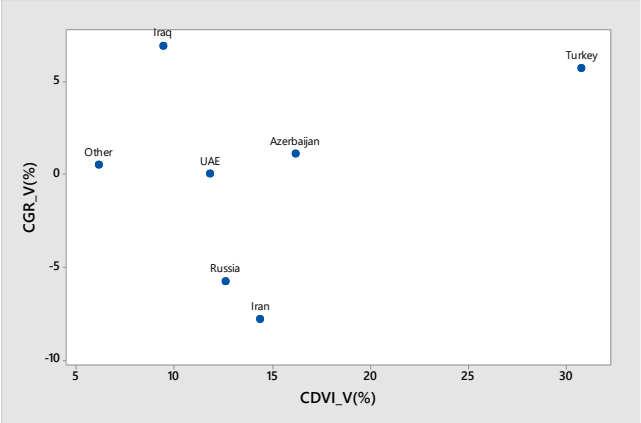
Source: Authors' Calculation Based on Sri Lanka Tea Board Statistics (2023)

The matrix relationship between growth rate and instability in terms of export volume and earnings were demonstrated in Fig. 5 and Fig. 6 respectively.



Source: Authors' Compilation

Fig. 5. Compound annual growth rate vs instability index an emphasis on tea export volume



Source: Authors' Compilation

Fig. 6. Compound annual growth rate vs instability index an emphasis on tea export earnings

(1) High growth and low instability (Highly Preferable): Iraq was recorded in this highly desirable category which has high growth rate and low instability in terms of both volume and earnings of Sri Lankan tea exports. Azerbaijan with respect to quantity of tea exports fall under this category while other countries fallen to this category in terms of value of exports.

(2) High growth and high instability (This category is preferable based on the magnitude of growth over instability index): of major importing countries only Turkey in both tea export quantity and earnings, has fallen into this category. Further, Azerbaijan in terms of value of tea exports fall into this category.

(3) Low growth and low instability (Less Preferable): Among major importers, Russia and Iran was reported under this category with respect to tea export quantity and earnings. These countries were less desirable for Sri Lankan tea exports. Other countries were fallen in to this class in terms of the tea exports volume while UAE was fallen to this category in terms of export value.

(4) Low growth rate and high instability (Not Preferable): UAE with respect to quantity of exports fallen to this group. Therefore, different approaches and strategies are required to increase the growth rate and to reduce the instability.

G. Export Market Share of Sri Lankan Tea in Global Trade

Export market share of top three leading tea exporters for each HS code category of tea exports (HS 0902, HS 090210, HS 090220, HS 090230 and HS 090240) and Sri Lanka were calculated based on the recently available data on ITC Trade Map. The results were depicted in Tab. 7.

TABLE 7: WORLD MARKET SHARE OF TOP THREE LEADING TEA EXPORTERS AND SRI LANKA'S POSITION IN GLOBAL TRADE

Commodity	Country 1	Country 2	Country 3	Sri Lankan Rank in Global Trade
Tea (HS 0902)	China (26.65)	Sri Lanka (16.13)	Kenya (13.82)	**2 (16.13)**
Tea, green (HS 090210)	China (56.41)	Japan (7.25)	Germany (4.51)	**5 (3.76)**
Tea, green (HS 090220)	China (68.01)	Vietnam (10.12)	Japan (7.61)	**11 (0.43)**
Tea, black (HS 090230)	Sri Lanka (27.72)	China (11.99)	United Arab Emirates (10.91)	**1 (27.72)**
Tea, black (HS 090240)	Kenya (29.67)	Sri Lanka (18.48)	India (14.50)	**2 (18.48)**

Note: Figures in Parenthesis Indicated Percentage Share of World Export in 2021(in Value term US$)
Source: Authors' Calculation Based on ITC Trade Map Data, (2023)

In the year 2021, China was the leading tea exporter in the world and it was followed by other major tea exporting nations such as Sri Lanka, Kenya, India, and the United Arab Emirates. Sri Lanka was the market leader of black tea exports, in the packaging category not exceeding three kilograms (090230), in 2021. Further, Sri Lanka ranked in second place in the same year, in terms of black tea exports, in packaging exceeding three kilograms (090240).

China was the leading export nation of green tea exports in year 2021. Sri Lanka ranked fifth in the same year with green tea exports in packaging not exceeding 3 kilograms (090210) valued at 51,112 US $ Thousand. However, in year 2021 Sri Lanka ranked in 11 in terms of green tea exports in packaging exceeding three kilograms (090220).

H. Export Competitiveness of Tea Exports of Sri Lanka

Mean scores of the Revealed Comparative Index (RCA), Revealed Symmetric Comparative Index (RSCA), and Trade Balance Index (TBI) for leading tea exporters in the world were calculated by using secondary data from 2011 to 2022. Product mapping was obtained by combining the both mean values of RSCA and TBI Indices. Mean scores of all indices and product mapping were exhibited as follows.

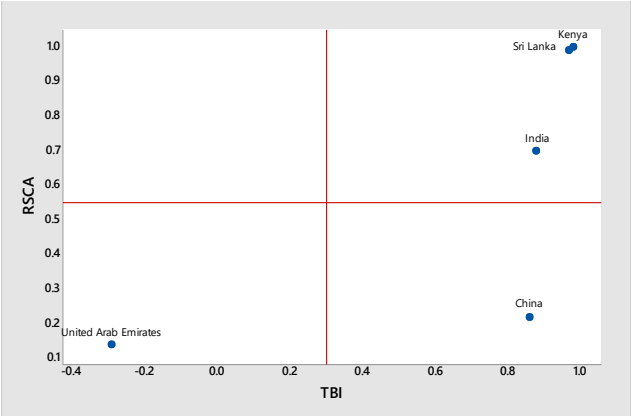
TABLE 8: MEAN SCORES OF RCA, RSCA, TBI FOR LEADING TEA EXPORTERS IN WORLD (2011-2022)

Country	Mean Values		
	RCA	RSCA	TBI
China	1.57	0.22	0.86
Sri Lanka	**314.11**	**0.99**	**0.97**
Kenya	497.27	1.00	0.98
India	5.71	0.70	0.88
United Arab Emirates	1.31	0.14	-0.29

Source: Authors' Calculation Based on ITC Trade Map Data, (2023) and World Development Indicators, (2023)

Tab. 8 depicts the mean scores of RCA, RSCA, and TBI indices for the top five tea exporters in the world for 2011-2022. According to the RCA index results all countries have a comparative advantage in exporting tea (0902). Kenya (497.27) indicates the highest RCA value for tea exports from 2011 to 2022 while United Arab Emirates (1.31) indicates the lowest RCA for total tea exports. Kenya (1.00) shows the highest RSCA value while United Arab Emirates (0.14) indicates the lowest comparative advantage among them. TBI values show the competition level of tea trade among leading exporting countries during the study period. All countries except United Arab Emirates show positive values while Kenya (0.98) became the first place in tea exporting having the highest TBI value. According to TBI values United Arab Emirates shows very poor export competitiveness among leading tea exporters.

Sri Lanka, Kenya, and India have a comparative advantage in tea exports and export specialization. Therefore, they are net exporters belong to Group A. China has comparative disadvantage and have export specialization. Therefore, net exporter belongs to Group C. United Arab Emirates has comparative disadvantage but no export specialization. Therefore, it can be known as a net importer and belongs to Group D.



Source: Authors' Calculation
Fig. 7. Product mapping for tea export competitiveness

IV. Conclusion

This study found that the total tea extent has increased while total tea production of Sri Lanka has decreased during the period from 2011 to 2022. In the same period, tea exports had negative growth while tea export value has depicted positive growth. The highest tea export quantity was seen during the year 2014 and this may be owed to the utmost tea production in the preceding year and programmes such as subsidy schemes and extension programmes implemented by Sri Lanka Tea Board. Consequently, the lowest tea export quantity was in the year 2022 due to the lowest tea production resulted from the shortage of agrochemicals and fertilizers. However, the highest value in export earnings was in the same year and this may be due to Sri Lankan Rupee (LKR) depreciation and high demand during the year 2022.

In this context, Sri Lankan tea production in terms of both quantity and quality should be improved in order to increase the growth of tea export quantity. Total tea production by elevation and process can be improved by implementing financial support schemes and agricultural extension programmes. These types of programmes can be implemented by the government and Sri Lanka Tea Board. Further, varietal improvement can be done by the Sri Lanka Tea Research Institute.

All tea export types by the process which are named as black tea, green tea, and instant tea exports show low instability. When considering category-wise tea exports, exports of tea packets (> 3 kg) showed the highest growth rate throughout the period with effect from January 2011 to December 2022 while exports of tea packets (1 kg - 3 kg) showed the highest instability. Further, there is a high interest in value-added tea products in the modern world. Hence, more research and development projects should be conducted on value addition.

The major import destination-wise results exhibited that Iraq has shown the highest positive growth rates in tea export volume and earnings. Further, it was revealed that Iraq was the most stable market for Sri Lankan tea exports because it had a high compound annual growth rate and low instability throughout the study duration (2011-2022). Moreover, Iraq has fallen into the top ten importing countries of Sri Lankan tea for more than two decades. According to the recent statistics obtained from the Sri Lanka Tea Exporters Association, Iraq has remained in the highest position for the period with effect from January 2023 to June 2023.

As a leading tea producer and exporter Sri Lanka should apply suitable export promotion strategies to evolve in existing stable markets and find potential markets for Ceylon tea. For example, by having bilateral trade agreements and introducing trade representatives, Sri Lanka can increase its market share in export destinations.

The findings of the RCA, RSCA and TBI indices are closely compatible with each other throughout the study period. Sri Lanka, Kenya and India have a comparative advantage in tea exports and have export specialization. Therefore, they are net exporters in world tea export market. Moreover, further research efforts should be made to analyze determinants that affect the Sri Lankan tea export competitiveness.

Acknowledgment

The authors wish to express their gratitude to all officials in the Sri Lanka Tea Board who provided secondary data and other relevant qualitative information for the success of this study.

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2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

Effective Utilization of Black Soldier Flies Larvae (*Hermetia illucens*) as a Poultry Feed: A Review

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***Abstract*—The use of food that can be consumed by humans as animal feed has become a major problem in today's world. In 2020, one out of every three people will fail to get enough food on a daily basis. Therefore, the carbohydrates, vitamins, and micronutrients essential for physical activity provided by grains have become unavailable in humans. Consequently, it is crucial for the global community to prioritize the development of substitutes for poultry, and other animal feeds. (BSF) The larval stage of this insect offers a remarkable source of protein, presenting a potential path to replace conventional poultry feed derived from grain resources. Research is being conducted on the use of this protein sources, and it is important to solve these problems and produce animal feed that can be obtained by the animal without shortage and at a low cost to the animal keeper. This offers an optimal remedy for countries such as Sri Lanka, which heavily rely on foreign imports for animal feed. This review emphasizes the introduction of the BSF as a means of developing an equitable resolution, not only for Sri Lanka but also for the global population of chicken and other poultry species.**

Keywords*—Black solider fly larvae (BFSL), animal feed ingredient, grains, poultry, Sri Lanka

I. INTRODUCTION

The poultry sector is a fast-growing and flexible industry that is essential for the livelihood of resource-poor farmers. It contributes to improving human nutrition, generating income, and providing manure for crop production. The sector has experienced significant growth and plays a crucial role in the livelihoods of one billion of the world's poorest people [1]. However, in the global economic context, using grains intended for human consumption as animal feed is not a justifiable practice. Approximately one-third of the annual global grain production is designated exclusively for animal feed [2]. The majority of poultry farm owners worldwide continue to use commercial chicken feed without any apparent decrease. In developing countries, large poultry farms are frequently established by feed companies, making them reliant on commercial poultry feed right from the start. This dependence on imported poultry feed or its components become a noticeable economic challenge in resource-constrained regions like Sri Lanka when trying to secure essential nourishment [3, 4]. Instead of depending on imported feeds, it's more cost-effective to create our own animal feed using affordable ingredients. Protein is generally the most expensive feed ingredient in poultry feed. Contemporary poultry feeds primarily comprise grains, soybean oil meal, minerals, and vitamins as protein supplements [5]. Hence, the BSF emerges as an elegant solution to conserve essential grains for the burgeoning global population while furnishing a protein source for poultry [6]. The imperative establishment of a sector centered on BSF larvae -based feed underscores the growing significance of this innovative approach in the animal feed industry. However, to realize its substantial potential, a conducive environment that entails enhanced government support, cost-effective investment, minimized operational expenses, improved regulatory coordination and heightened consumer acceptance is required [7].

The multifaceted utility of the BSF extends beyond its application as an animal feed. This remarkable insect has already been harnessed for organic waste management on a global scale [8], offering substantial potential as a viable solution for addressing the staggering 1.3 billion metric tons of food waste [9]. This helps minimize the negative impacts of such practices, including air and water pollution, land degradation, methane and hazardous leachate emissions, and climate change [10]. Exploring this topic, the aim of this article is to demonstrate how the use BSF can significantly improve the feed supply in the poultry industry.

II. BLACK SOILDER FLY

The BSF, scientifically known as *Hermetia illucens* (Linnaeus, 1758),) (Diptera: Stratiomyidae), is a synanthropic and polysaprophagous insect indigenous to the Neotropics. Over the years, it has undergone extensive global dispersion, extending its habitat to virtually all zoogeographic regions, particularly in warmer climates [11, 12]. BSF belong to the Stratiomyidae family, which encompasses approximately 2700 species [13]. These flies adults characterized by their medium size and predominantly black coloration, with certain body parts displaying can range from combinations of metallic reflective colors such as blue-green [14]. Adults have a compact head, notably slenderer than the body, with widely separated eyes. Its head is shiny black, with a white stripe running along the lower facial region banking the eyes. The dark brown to black antennae have eight segments, with the final segment flattening. The BSF has

a sponge-like, liquid-feeding mouthpart, which is typical of non-biting flies [15, 16, 17]. Male and female adults have unexplored transparent 'windows' on their first abdominal segment. The function of which has not yet been definitively studied, but these may serve several purposes, including thermoregulation and communication, or simply be a result of the structure of its exoskeleton. Adults measure 16-17 mm in length, 2.8-3.8 mm in width and 0.220 g (low) in mass [18]. Sexual dimorphism is evident in Bl, with females typically larger than males. Females display varying patterns on the head and spot sizes on the abdomen. Male genitalia, the aedeagal complex, are slender with basal dilation. Female genitalia have external features known as terminalia, which are characterised by long cerci segmented into two parts (Scissor-like structure). The genital furca exhibits a subtriangular shape with proximal pointed ends, a significant median aperture, and broad, leaf-shaped posterolateral projections [19,20].

III. Importance of BSF In Poultry Feed

An immediate imperative exists for Sri Lanka and the global community to seek alternative sources of animal feed, distinct from traditional grains. The consequence of not doing so may entail a future marked by food scarcity affecting both human and animal populations. This urgency arises not only from population growth but also from the escalating impact of daily worsening weather and climate changes worldwide.

Until recently, eggs were the cheapest source of animal protein available for human consumption in Sri Lanka. However, since 2022, it has escaped the "cheap" label because the price of an egg has increased to Rs.62 per egg since August 2023, and the price of a kilo of chicken has increased to Rs. 1300 [21]. This is a huge amount of money even if you look at the daily expenses of the poor people of Sri Lanka and the common people. The primary factors behind this situation were the insufficient "Maha season" maize harvest in Sri Lanka and the substantial expenses incurred by chicken feed producers' due to maize imports. Consequently, the sharp rise in egg prices, in particular, triggered a significant shift from direct consumption to mass-scale bakery products. This shift, coupled with the subsequent unavailability of the most economical protein source, acted as a catalyst for malnutrition [22].

A. As a High-Protein Poultry Feed.

BSF larval meal emerges as a promising alternative for nutrient-rich and sustainable animal feed, replacing costly and limited protein sources like fishmeal and soybean meal. The insects considered appropriate for animal feed should be capable of large-scale industrial rearing, producing at least 1,000 kg insect fresh weight daily [23]. When quantifying the crude protein content within BSF dried powder (100 g), it is expressed within a specific range, typically falling between 39% and 49% based on research findings [24]. The variability in this range is attributed to the substrate used. According to the available source data, the median crude protein content was approximately 45.01±0.19% [25].

Today, poultry farming mainly focuses on egg-laying hens and broilers for meat production [26]. The protein content in the diet for broiler (Tab. 1) and egg - laying hens (Tab. 2) fluctuate based on their age. A young laying hen typically consumes approximately 100–150g [27] of poultry feed and a five-week-old broiler consumes approximately 1200–1300 g [28]. According to the table data, only approximately 50% of BFS is required to provide the daily protein requirement of chickens.

TABLE 1

Protein requirement [29] of broilers (Ross 308) according to their age and the protein percentage of chicken feed for the respective age in the world [30] and in the Sri Lankan [31] market (100g).	**Age (days)**		
	1 - 10	11 - 24	25 - slaughter
Protein requirement of broiler per day (min %)	22 – 25	21 – 23	19 – 21
Protein content of traditional broiler chicken feed in the global market (min %)	21.95	20.92	19.90
Protein content of broiler chicken feed in the Sri Lanka (min %)	23.0	21.5	19.5

TABLE 2

Protein requirement [32] EU red laying hens, according to their age and the protein percentage of poultry feed [33] for the respective age in the global market (100g).	**Age (weeks)**			
	1 - 5	6 - 10	11 -16/17	18 - 50
Protein requirement of red egg laying breed per day (min %)	2	20	16	18
Protein content of traditional layer chiken feed in the global market (min %)	19.09	17.07	15.38	18.25

B. Supplementing Other Nutritional Needs of Poultry

Apart from proteins, there are also other nutrient and vitamins that are required for poultry [34, 35]. They are also mostly contained in BFSL (Tab. 3).

TABLE 3

Daily nutritional requirements of broiler and laying hens and dry BSFL nutritional value.	**For broilers between 11 and 24 days old**	**for laying hens between 18 and 50 weeks old**	**Dried BSFL powder (100g)**
Crude fibre, % (Max.)	5.00	9.00	8.95
Ash, % (Max.)	2.50	4.00	7.91

Amino acids are crucial for sustaining physiological functions in animals. Some amino acids are categorized as essential because the animal body cannot synthesize them and must acquire them through the diet. These include cysteine, histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, tyrosine, and valine.

Non-essential amino acids, such as glutamine, glutamate, proline, glycine and arginine, can be synthesized by the animal body from other amino acids. Insect proteins are highly sought after for their well-balanced and adaptable amino acid profiles. BSF represent a promising insect protein source for animal feed. Nevertheless, BSF may lack specific essential amino acids (Methionine + Cystine) and may require supplementation with other protein sources or synthetic amino acids to achieve an optimal balance in diet formulations and fulfill amino acid requirements.

BFSL exhibit an approximate lipid content of 30% on a dry matter basis [36], and this lipid composition varies depending on the specific growth media employed. The utilization of BSF in food waste environments led to a prepupae fatty acid composition prominently characterized by a high concentration of lauric acid. This abundance of lauric acid [37] is notably elevated in larvae cultivated on fruit-based substrates (52%) [38]. Larvae demonstrates the capacity to biosynthesize lipids using the available carbohydrates within the substrate [39]. The protein content of younger larvae, harvested at an early developmental stage, is notably elevated, whereas as the larvae matures, their lipid content proportionally increases [40, 41]. Fatty acids of BSF larvae grown in a fruit substrate medium were as follows: Lauric Acid (C12:0)–76.13, Myristic Acid (C14:0)–8.46, Palmitic Acid (C16:0)–6.98, Oleic Acid (C18:1n-9)–4.97 [42].

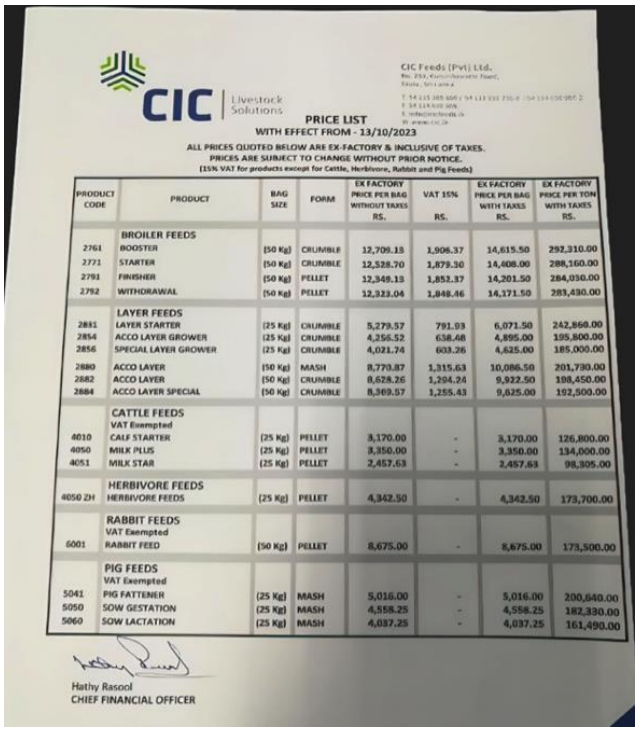
Considering the aforementioned facts, BSF can be recommended as a viable option to supply both macro and micro nutrients while offering it as a preferred feed for poultry. Insect eating is a bird's natural behavior Birds are omnivorous and like to catch and eat more live things. Feeding live larvae to chickens elicits increased feed intake and weight gain due to the larvae's motion capturing the birds' attention [43].

C. The Cost of Poultry Feed Can Be Greatly Reduced

The global poultry feed market, valued at USD 175.9 billion in 2018 with a 4.5% CAGR, is primarily driven by the increasing demand for chicken meat and eggs worldwide. Poultry is an economical source of protein, and its demand is influenced by population and income levels. Packaged poultry feed is growing faster than traditional feed, offering new opportunities.

Quality and pricing of the feed are significant factors. Key players include Cargill, Archer Daniels, Midland, Kemin Industries, and Lallemand, Inc. In the livestock sector, broilers account for over 65% of the market, primarily for meat production, while layers, contributing about 30%, are reared for egg production. High consumption of eggs and population growth drive the layer segment. Regions such as the United States, Mexico, and Canada are prominent markets for poultry products. The diminishment of arable land, water scarcity, fertilizer constraints, climatic perturbations, and geopolitical conflicts will likely exacerbate global grain prices. Consequently, there will be a commensurate escalation in the cost of animal feed.

Due to the increase in the price of animal feed in the Sri Lankan market, the purchase of products made by turning eggs and meat into ingredients has increased. Today, in the Sri Lankan market, layer starter (25 kg)–Rs. 6,071.50, layer grower (25 kg)–Rs.4895, layer special (50 kg)–Rs. 9625, broiler booster (50 kg)–Rs. 14,615.50, broiler starter (50 kg)–Rs. 14,408, broiler finisher (50 kg)–Rs. 14,201.50 (Fig. 1).



CIC Livestock Solutions

CIC Feeds (Pvt) Ltd.

PRICE LIST
WITH EFFECT FROM - 13/10/2023

ALL PRICES QUOTED BELOW ARE EX-FACTORY & INCLUSIVE OF TAXES.
PRICES ARE SUBJECT TO CHANGE WITHOUT PRIOR NOTICE.
(15% VAT for products except for Cattle, Herbivore, Rabbit and Pig Feeds)

PRODUCT CODE	PRODUCT	BAG SIZE	FORM	EX FACTORY PRICE PER BAG WITHOUT TAXES RS.	VAT 15% RS.	EX FACTORY PRICE PER BAG WITH TAXES RS.	EX FACTORY PRICE PER TON WITH TAXES RS.
	BROILER FEEDS						
2761	BOOSTER	(50 Kg)	CRUMBLE	12,709.15	1,906.37	14,615.50	292,310.00
2771	STARTER	(50 Kg)	CRUMBLE	12,528.70	1,879.30	14,408.00	288,160.00
2791	FINISHER	(50 Kg)	PELLET	12,348.13	1,852.37	14,201.50	284,030.00
2792	WITHDRAWAL	(50 Kg)	PELLET	12,323.04	1,848.46	14,171.50	283,430.00
	LAYER FEEDS						
2851	LAYER STARTER	(25 Kg)	CRUMBLE	5,279.57	791.93	6,071.50	242,860.00
2854	ACCO LAYER GROWER	(25 Kg)	CRUMBLE	4,256.52	638.48	4,895.00	195,800.00
2856	SPECIAL LAYER GROWER	(25 Kg)	CRUMBLE	4,021.74	603.26	4,625.00	185,000.00
2880	ACCO LAYER	(50 Kg)	MASH	8,770.87	1,315.63	10,086.50	201,730.00
2882	ACCO LAYER	(50 Kg)	CRUMBLE	8,628.26	1,294.24	9,922.50	198,450.00
2884	ACCO LAYER SPECIAL	(50 Kg)	CRUMBLE	8,369.57	1,255.43	9,625.00	192,500.00
	CATTLE FEEDS VAT Exempted						
4010	CALF STARTER	(25 Kg)	PELLET	3,170.00	-	3,170.00	126,800.00
4050	MILK PLUS	(25 Kg)	PELLET	3,350.00	-	3,350.00	134,000.00
4051	MILK STAR	(25 Kg)	PELLET	2,457.63	-	2,457.63	98,305.00
	HERBIVORE FEEDS						
4050 ZH	HERBIVORE FEEDS	(25 Kg)	PELLET	4,342.50	-	4,342.50	173,700.00
	RABBIT FEEDS VAT Exempted						
6001	RABBIT FEED	(50 Kg)	PELLET	8,675.00	-	8,675.00	173,500.00
	PIG FEEDS VAT Exempted						
5041	PIG FATTENER	(25 Kg)	MASH	5,016.00	-	5,016.00	200,640.00
5050	SOW GESTATION	(25 Kg)	MASH	4,558.25	-	4,558.25	182,330.00
5060	SOW LACTATION	(25 Kg)	MASH	4,037.25	-	4,037.25	161,490.00

Hathy Rasool
CHIEF FINANCIAL OFFICER

Fig. 1. Lives stock feed price list October 2023

However, BSFL can save this amount and grow it on wasted kitchen waste and crop residues, thus managing waste and making poultry farming more profitable. In addition, because this larva can be raised in vertical racks in a small amount of space, the production of one type can be developed as an additional source of income for the poultry farmer. It is easy to use because it is not toxic with other foods, and this fly can be found in more countries around the world. Moreover, it is easy for any common poultry farmer to start this business, there is a high demand for BFSL protein in the world market, it can be used to fill the protein needs of humans [44]. BSF has a short life span and large body size, and has very high feed conversion efficiency [45]. Using BSFL is a highly cost-effective approach that has already been successfully implemented. Positive outcomes from these endeavours offer compelling evidence applicable to both developing and developed nations. Indeed, this is a **"Black diamond"** in the animal feed industry.

IV. BSFL Growing Steps for Sri Lanka

Sri Lanka is, classified as a developing nation, as it heavily relies on importing substantial quantities of grain for plant-based protein as animal feed, as elaborated in the fourth section of this article. The protein content typically falls within the range of 10% to 15%, with the highest concentration of protein [46] residing in the storage proteins, such as prolamins, globulins, and germins [47]. Because of that Poultry farmers need to be informed about the potential establishment of BSF as a viable solution to address Sri Lanka's economic challenges stemming from significant expenditures on grain imports from other nations and the resultant surge in egg prices due to escalating costs of chicken feed. It is imperative to emphasize that relying solely on egg imports from India is not a sustainable resolution [48]. When establishing a BSF rearing facility, whether on a large or small scale, the initial step involves the construction of an adult fly rearing enclosure, often referred to as a "mating cage" or "love cage. On a smaller scale, this enclosure can be crafted from materials like wooden framing with a fine nylon mesh [49] covering, meticulously designed to prevent fly escape. Subsequently, it is crucial to introduce female and male flies into the enclosure in a controlled ratio of 40% females to 60% males. This controlled environment promotes successful mating and egg production in a BSF rearing operation [50]. Adult BSF flies do not require solid food; they only require water. To enhance their vitality, providing a water source with a slight sugar solution can be beneficial [51]. It is essential to ensure that the water source is provided in a manner that avoids direct contact with the flies, as any physical disturbance may lead to accidental immersion and mortality in the water. The female BSF typically lays an egg cluster containing 540 to 1505 eggs [52], displaying a distinct yellow-cream colouration. When laying these eggs, the BSF seeks a suitable crevice in close proximity to the organic matter. The eggs are meticulously placed within the Substrate and this process can be aided by using a wooden strip or cardboard.

This process involves the construction of a structure capable of accommodating organic material within a tray. The eggs, measuring approximately 1 mm in length, are incubated for approximately 4 days to produce larvae. During the first four days, these larvae exhibit a cream-white colouration and experience their most rapid growth within an approximately 11–day span. Male larvae typically attain a length ranging between 17 and 18 mm, whereas their female counterparts achieve lengths of 21–23 mm. Their diet primarily consists of organic sources such as vegetables, fruits, fish waste, kitchen scraps, fibrous waste, almond hulls, rice straw, high-moisture feed, and livestock and poultry manure [53]. After the 13 to 18 days good for harvest larvae, this phase referred to as the "prepupae" period. During this preparatory phase, the larvae consume an amount of food equal to twice their body size. Subsequently, the prepupa are subjected to a drying process, which can be achieved through mechanical or high-temperature methods to retain moisture content, ultimately converting them into a powder. This powder can be used for both animal and human consumption, and live larvae can be employed as feed for free-ranging poultry.

Furthermore, scientific inquiries are underway to examine various proportions and formulations of chicken feed blended with BSFL for improved sustainability and resource efficiency in poultry nutrition [54].

V. Conclusion

The use of BSFL (*Hermetia illucens*) as poultry feed presents a promising and sustainable approach to enhance global and Sri Lankan grain preservation for human consumption. As the world faces increasingly dire issues of grain wastage for poultry feeds, such innovative solutions are urgently needed to address the problem. By harnessing the potential of BSFL as alternative protein and nutrient sources for poultry, this strategy not only reduces the pressure on traditional grain resources but also aligns with the imperative to minimize grain wastage. Moreover, this eco-friendly approach underscores the significance of interdisciplinary scientific collaboration, offering a potential blueprint for a more resilient and sustainable future in agriculture and food production. Further research in this area is essential to uncover additional nuances and optimize the utilization of these resources to maximize their impact on grain preservation and food security.

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2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

Public Opinion on Waste Electrical and Electronic Equipment (WEEE) Management in Colombo, Gampaha, Galle, Kandy, and Matara (Sri Lanka): A Case Study

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***Abstract*—The significant issue at hand is the alarming surge in waste resulting from the use of Electrical and Electronic Equipment (EEE), which, due to its non-biodegradable nature, poses a substantial threat to society. In light of this, this study aimed to assess the level of public awareness regarding e-waste management. A survey employing a questionnaire was carried out to collect data regarding public opinion on the management of WEEE. The survey involved 99 respondents from five different districts. The research findings indicate that 70% of Matara respondents are informed about E-waste management policies. Furthermore, 61% of respondents in Galle, 50% in Colombo, 43% in Gampaha, 35% in Kandy, and 34% in Matara are aware of the potential risks linked to WEEE. The results reveal that 53.8% of respondents practice E-waste segregation, while 50% in Colombo and Gampaha resort to burying E-waste at their residences. Notably, 19% of respondents in Galle opt for compost bins, and 25% in Kandy and Matara choose to sell electronic waste to collectors. Environmental and human health impacts of WEEE are known by just 50% of the respondents from Colombo, 43% in Gampaha, 61% in Galle, 35% in Kandy, and a mere 34% of the respondents in Matara. While all respondents in Colombo are knowledgeable about businesses that collect recyclable materials, a larger segment of the respondents in Gampaha (68%), Galle (53%), Kandy (85%), and Matara (65%) seem to be unaware of such services. A comprehensive approach is essential for addressing environmental challenges associated with WEEE.**

Keywords—Waste management, electrical and electronic equipment, e-waste, regulations

I. INTRODUCTION

The continual development of technology leads to shorter product lifecycles and an ever-increasing pile of electronic garbage (e-waste), which is created. Metals, polymers, glass, and chemicals, which are hazardous and not biodegradable, are among the diverse materials in these gadgets. Due to the seeping of harmful compounds into soil and water sources, improper disposal, which frequently ends up in landfills or incinerators, can cause environmental degradation and health concerns. Waste management is a critical global challenge, and Sri Lanka [1, 2] is currently grappling with the emergence of electronic waste (e-waste) as a significant component of its waste stream. Waste management is a critical global challenge, and Sri Lanka is currently grappling with the emergence of e-waste as a significant component of its waste stream [5].

In 2016, e-waste accounted for approximately 0.2% of municipal solid waste (MSW), and it was projected to increase due to the growth of urbanization and improvements in the quality of life [3]. E-waste is categorized into two main groups: white goods, such as refrigerators, washing machines, air conditioners, electric ovens, and toys, which consist of materials that can be readily recycled locally and contain fewer hazardous components; and non-white goods, including computers, televisions, printers, and mobile phones, which contain significant amounts of hazardous materials, as identified by EML in 2016 [4].

Moreover, according to the "global overview report for digital 2022," device ownership figures indicate the following: 96.6% use some form of mobile phone, 96.2% use a smartphone, 8.8% use a feature phone, 63.1% use a laptop or desktop computer, 34.8% use a tablet device, 20.3% use a gaming console, 27.4% use a smartwatch or smart wristband,

15.5% use a TV streaming device, 14.1% use a smart home device, and 4.8% use a virtual reality device. Consequently, electronic waste is increasingly becoming a major concern in Sri Lanka [6].

To comprehensively understand the intricate aspects of household e-waste management, this research delves into the drivers of behavior within communities and the obstacles they face. Promoting sustainable practices, enhancing e-waste recycling rates, and mitigating the environmental repercussions resulting from household e-waste mismanagement are of paramount importance. Furthermore, gaining a deeper understanding of these trends is crucial for devising well-informed and effective solutions. Therefore, the driving force behind this research is our commitment to acquiring a comprehensive understanding of these critical aspects, primarily driven by the need to gauge public opinions on Waste Electrical and Electronic Equipment (WEEE) management in Sri Lanka. As e-waste continues to accumulate, our study seeks to explore the broader landscape of e-waste collection in the country. Specifically, we aimed to assess the level of public awareness about e-waste, the knowledge of proper e-waste disposal procedures, and the quantification of annual e-waste collections.

II. Materials and Methods

A questionnaire-based survey was conducted to collect data on public opinion on WEEE management, using a population of 99 respondents that was selected based on convenience sampling. For the survey, five districts were selected. These selected districts were Colombo, Gampaha, Galle, Kandy, and Matara (Fig. 1).

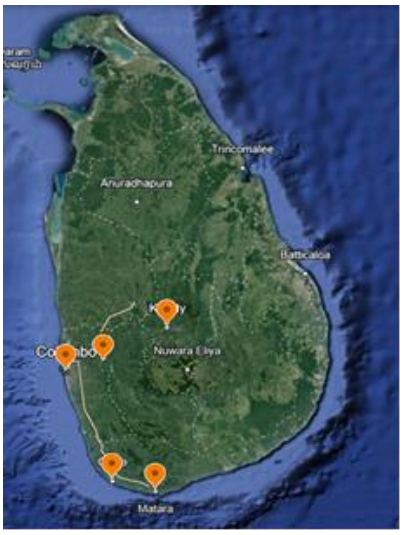

Fig. 1: Study area (Ref: Google Earth)

The survey was conducted using various electronic methods, such as email, Facebook, and WhatsApp, supplemented by personal phone calls over two months in September and October 2023. Additionally, in-person face-to-face interviews were also conducted. The questionnaire comprised with 35 questions; a mixture of Likert scale, multiple-choice, and open-ended questions. The 35 questions included personal information (Q1 - Q7), how they separate their garbage (Q8 - Q12), dispose of WEEE (Q13), factors to consider when purchasing (EEE) and do they separate (WEEE) (Q14 - Q19), one of the most important factors taken into consideration when WEEE dispose/collection,(Q20) Awareness on discarded e-waste re-cycling (Q21-Q22), Opinion of WEEE collection for dispose responsibility (Q23), awareness of hazards present in electronic products(Q24-Q26), source of information to dispose WEEE (Q27), like to participate E-Waste related collection or awareness programs (Q28-Q29), most important way to control WEEE pollution(Q30), awareness of e-waste management policy(Q31), If green products are available are they willing to pay additional for EEE(Q32-Q33), If the government wants to develop a good E-waste system, are they willing to pay a reasonable amount of disposal fee (Q34), Comments for improvement of WEE management in their area(Q35). Ethical clearance was obtained prior to the research due to the participation of human subjects in the study. Their demographic details and responses to the questions were collected only for the purpose of the study, and the respondents were informed about this at the beginning of the survey. All the respondents participated in the survey as volunteers. The respondents' consent was secured for their voluntary participation in the survey after informing the respondents about the purpose of the study and the potential dissemination of the outcome prior to the survey.

III. Results and Discussion

A. *Demographic Characteristics*

The age range of the test population was between 17 to 60 years. The majority of respondents (79.04%) were 20 - 30 years old. Nearly 8% and 13% of the respondents represented the age groups of 17-20 years and 30-60 years, respectively. Among the respondents, a majority were graduates and above level (32.1%), while 27.4%, 20.8%, and 9.4% were up to A/L, diploma & other, and professional degree, respectively. Furthermore, the majority of respondents (76.4%) had one family. The others are single-member families (14.2%) and extended families (9.4%). Considering the overall demographic characteristics, the test population is relatively young, well-educated, and has a variety of family structures.

B. Amount of Household Waste Generation

According to the research details, household wastes could be separated as kitchen waste (food/preparation waste), plastic and polythene, paper and cardboard, garden sweeping (leaves), Metal (Ion, Aluminium), glass and bottles, cloths and textiles, rubber/leather, other. According to the analysis results, most of the generated waste is less than 1 kg per day. Tab. 1 depicts the summary of the respondents' analysis for the quantity of household waste generation.

TABLE 1: SUMMARY OF QUANTITY WASTE GENERATION CAPACITY OF HOUSEHOLDS PER DAY

Type of Waste	**Percentage of Respondents (%)**			
Kitchen waste	<1kg/day	2-4kg/day	4-6kg/day	>6kg/day
Plastic, Polythene	44.44	39.39	15.15	1.01
Paper and cardboard	79.80	15.15	2.02	3.03

Garden sweeping	82.83	8.08	8.08	1.01
Metal	50.51	34.34	13.13	2.02
Glass and bottles	79.80	14.14	5.05	1.01
Cloths/old textiles	81.82	9.09	7.07	2.02
Rubber/leather	83.84	10.10	5.05	1.01
Other	81.82	14.14	3.03	0.00
Kitchen waste	79.80	14.14	4.04	2.02

C. WEEE Separation and Disposal

According to data collected from the respondent population on WEEE disposal, 53.8% of the population actively engaged in the separation of e-waste from other waste materials, demonstrating a notable commitment to responsible waste management. Meanwhile, 24.5% occasionally separate e-waste, and 17.9% do not engage in any form of e-waste separation at all, as illustrated in Fig. 2.

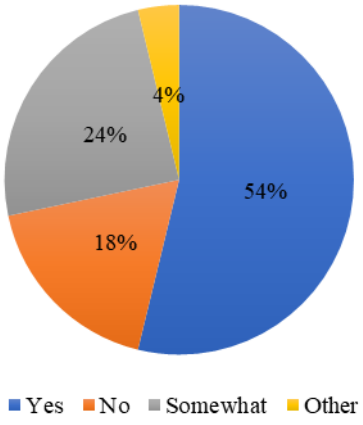

Fig. 2: Status of e-waste separation

Furthermore, according to the conducted research, respondents had prioritized certain key factors when selecting an electronic waste collector. Notably, 33% emphasize the convenience of accessing e-waste collectors, while 30.2% consider the collector's capacity for proper treatment and recycling, favoring formalized treatment processes. Additionally, 11.3% take into account any incentives provided by the collector, such as compensation or incentives, and 11% consider the price offered for their e-waste. Interestingly, a substantial portion of the respondents demonstrate limited awareness of electronic waste collection and recycling organizations. They largely attribute the primary responsibility for WEEE collection and disposal to local authorities (39.6%) and central government bodies (34.9%). Fig. 3 depicts the summary of factors that should be considered when selecting a suitable WEEE collector according to public opinion.

The study explores e-waste management behaviors and preferences among the surveyed population, revealing a growing environmental consciousness. Factors such as accessibility, responsible treatment, recycling capabilities, and incentives influence the selection of e-waste collectors. However, a knowledge gap exists regarding organizations involved in e-waste management and the role of government initiatives in promoting sustainable practices.

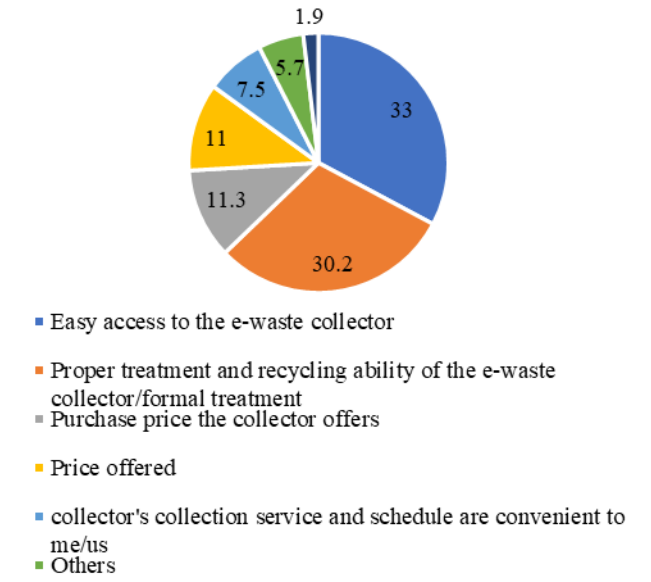

Fig. 3: Summary of public opinion regarding the WEEE collector selection

D. Waste Electrical and Electronic Equipment Disposal and Public Awareness About E-Waste Collection Companies

When considering the WEEE disposal methods, a significant number of respondents in Colombo and Gampaha (50%) indicated that they bury their e-waste in a pit at home. In contrast, 19% of respondents in Galle mentioned using a compost bin, while 25% of respondents in Kandy and Matara reported selling their electronic waste to collectors who visit their homes. However, the practice of burying electronic waste in a pit at home emerged as the most popular method. It is important to note that improper e-waste disposal practices, such as burying it at home, can lead to soil and water pollution, which has adverse effects on human health. Hence it is important to recycle the E-Waste and public awareness about those companies.

Interestingly, in Colombo, all respondents are well-informed about businesses that collect recyclable materials. However, in the other four districts, a higher proportion of people appear to be unaware of such services, with figures as follows: Gampaha (68%), Galle (53%), Kandy (85%), and Matara (65%). WEEE is considered valuable waste due to its content of valuable metal components that can be recycled and repurposed. To enhance efficiency, government regulations for the control and management of e-waste disposal and recycling can be formulated. A summary of the responses for public awareness about E-waste collection companies is shown in Fig. 4. As public awareness of the environmental impact of e-waste continues to rise, more individuals are recognizing the importance of proper management and disposal in contributing to a more sustainable environment.

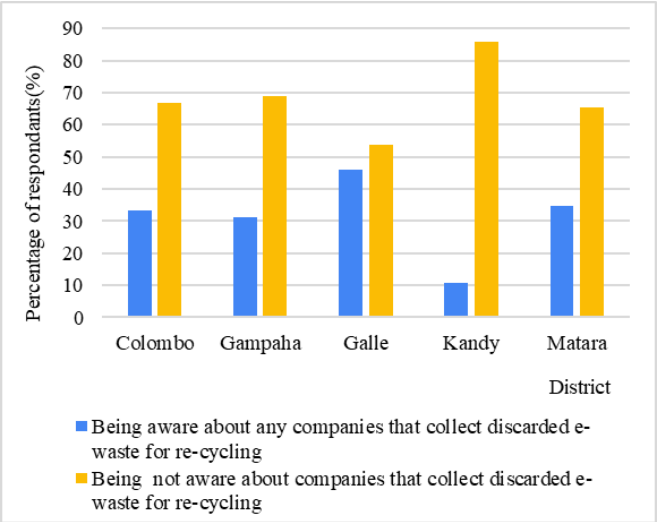

Fig. 4: Summary of public awareness about E-waste collection companies

E. *Awareness on WEEE and their impacts*

Based on the responses, it's evident that different regions exhibit varying levels of knowledge about the potential risks associated with electronic products. Colombo scored 50%, Gampaha 43%, Galle 61%, Kandy 35%, and Matara 34%. However, when considering the overall majority, it becomes apparent that a significant portion of the public is unaware of these risks. Despite the widespread use of electronic items in modern society, there remains a concerning lack of understanding regarding their potential impacts. This underscores the importance of increasing awareness and education in this area. The majority of respondents indicated that WEEE pollution has an impact on both the environment and human health. However, a notable percentage of respondents expressed the view that environmental contamination and harm to human health may not always be certain, and some respondents were also unaware of these potential concerns. Therefore, leveraging the cutting-edge communication tools available today, we can effectively engage with the public to educate them about these challenges. Fig. 5 and Fig. 6 depict the summary of the environmental impacts of WEEE.

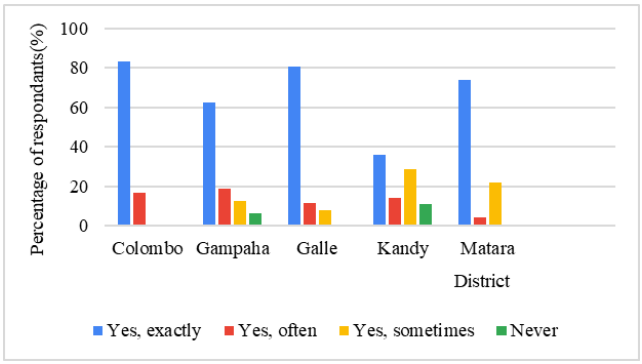

Fig. 5: Status of awareness about the environmental and human health impacts of Waste Electrical and Electronic Equipment

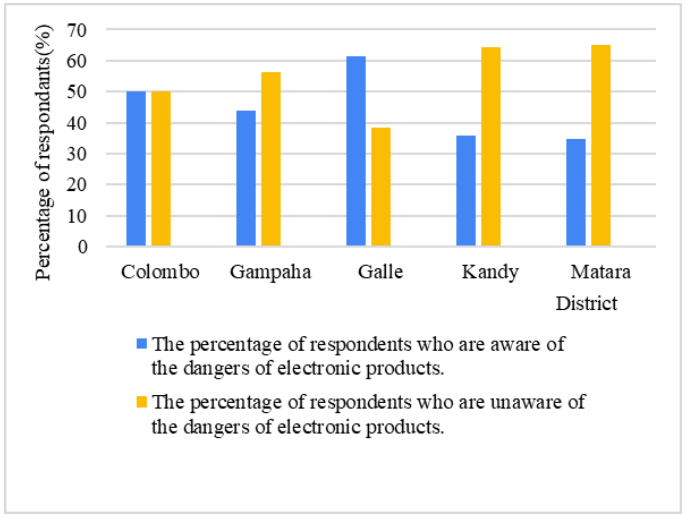

Fig. 6: Status of awareness about the hazards present in Electrical and Electronic Equipment products

F. *Public Preference for Alternative Usage*

When respondents were asked about the most effective way to control WEEE pollution, the preferences varied by region. In Colombo, the majority of respondents (50%) favored taking strict control over WEEE import as the preferred method for reducing WEEE pollution. In Gampaha, most responders believed that perfecting legislation, strict control over WEEE import, and enhancing public education on environmental protection (25%) were the best approaches. In Galle, the majority (34%) chose enhancing public education on environmental protection as their preferred method. In Kandy, 25% of those surveyed believed that enhancing public education on environmental protection was the most effective way to reduce WEEE pollution. Lastly, in Matara, a significant majority (69%) selected enhancing public education on environmental protection as their top choice for reducing WEEE pollution. When looking at the collective preference for enhancing public education on environmental protection, it's evident that a substantial number of respondents believe that modern society may not be sufficiently concerned about the negative environmental impacts resulting from human activities. This suggests a lack of comprehensive understanding of environmental harm, including the processes that lead to environmental contamination, the primary pollutants causing the most significant damage, and the potential consequences for future generations. Notably, a considerable portion of the population appears disinterested and indifferent to these pressing issues. It is crucial, first and foremost, to disseminate widespread knowledge about e-waste and its environmental consequences. Therefore, a prudent strategy may involve a combination of these methods to reduce WEEE pollution, with the support and participation of an informed community.

G. *Awareness of Regulations Related to EEE Usage*

Awareness of regulations related to Electrical and Electronic Equipment is one of the most important factors for WEEE management. According to the provided statistics, awareness rates regarding the government's e-waste management strategy vary across regions. Colombo has a 33.33% awareness rate, Gampaha 56%, Galle 65%,

Kandy 54%, and Matara 70%. The low levels of awareness in many areas suggest that the public may be insufficiently informed about the government's regulations concerning WEEE. This lack of knowledge can present significant challenges in recycling, managing, and controlling e-waste. Despite an understanding of the risks associated with e-waste, improper disposal practices persist due to a lack of awareness about regulatory requirements. This ignorance hinders the realization of the intended regulatory goals. Fig. 7 depicts the Summary of public awareness about E-waste management policy in Sri Lanka.

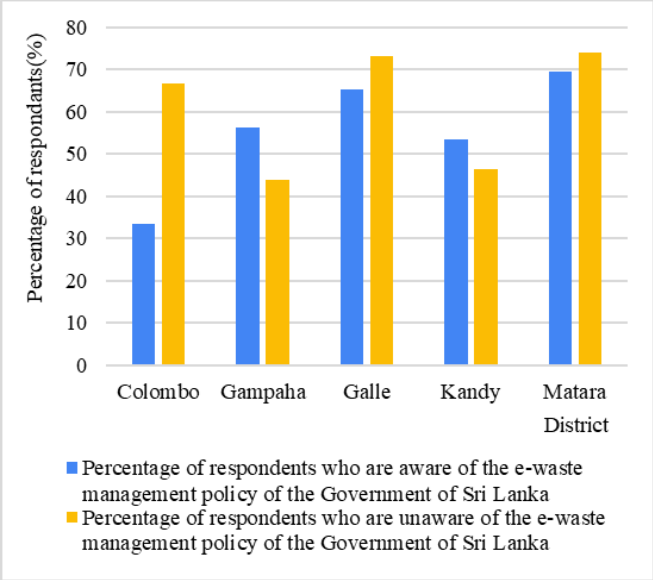

Fig. 7: Summary of the public awareness about e-waste management policy in Sri Lanka

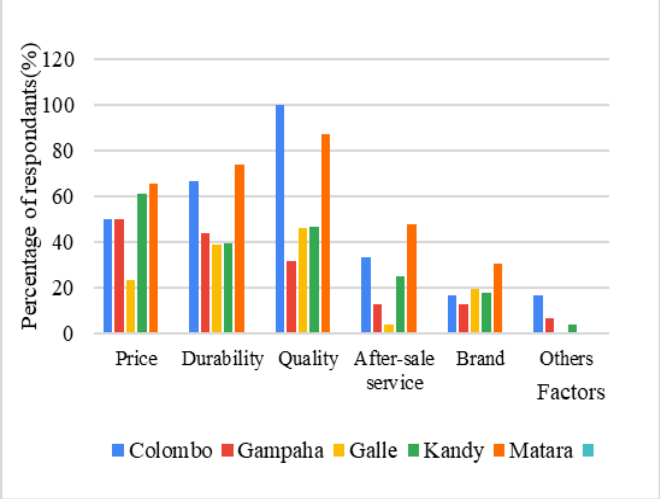

Fig. 8: Summary of the factors that respondents consider for electrical and electronic equipment (WEEE) replacement

Improving energy efficiency and removing hazardous and substandard equipment can be achieved by ensuring that electrical and electronic equipment comply with relevant standards and by raising awareness in society. When inquiring about the primary factors influencing replacement decisions for Electrical and Electronic Equipment, price, overall quality, durability, and product safety were consistently ranked as the top considerations for most individuals. Educating the general public about these criteria empowers consumers to make informed choices, selecting products that are not only safe and compliant with standards but also more energy-efficient and less likely to interfere with other electrical systems. Fig. 8 depicts the summary of the factors that public considers for Electrical and Electronic Equipment replacement.

H. Recommendation to Reduce EEE Pollution

The survey respondents were asked to provide recommendations for reducing the usage and pollution associated with EEE. In the Matara area, suggestions included the need for heightened public awareness through educational campaigns on the proper disposal of electronic waste, the implementation of regulations using stickers to discourage illegal dumping, promotion of WEEE compound recycling to minimize environmental impact, encouragement of manufacturers to design products with recycling in mind, establishment of a system for collecting WEEE from households and businesses, and some individuals preferred taking personal responsibility over government management. In Kandy, there was a call for a more effective and systematic approach, with recommendations for the government to provide separate bins in public places for e-waste, establishment of local recycling companies for the benefit of the community, and a strong emphasis on the government's responsibility in addressing this issue. In the Galle area, the primary recommendation was the establishment of a regular mechanism for collecting WEEE. Lastly, comments from the Gampaha and Colombo areas stressed the importance of proper recycling of all waste materials and highlighted the role of the government in collecting separated waste.

IV. Conclusion

The use, disposal, and eventual recycling or rehabilitation of electronic equipment encompass a range of behaviors associated with household e-waste management. Understanding these behaviors is crucial for the development of effective awareness campaigns, data collection methods, and policy initiatives. Variables such as the availability of disposal alternatives, knowledge of recycling facilities, financial incentives, and social norms can all influence household behavior when it comes to managing e-waste. In many households, there is a widespread lack of knowledge about the potential impact of e-waste and the available options for proper disposal. Often, the convenience factor plays a significant role, leading people to choose the simplest disposal methods without considering the environmental consequences. Accessibility to recycling facilities can also pose a barrier to proper e-waste disposal. Additionally, community behaviors can be influenced by monetary incentives and educational programs aimed at promoting ethical e-waste management practices. In conclusion, the results of the "Public Opinion Survey on WEEE Management" underscore the diverse perspectives and recommendations of the survey respondents. Notably, there is an urgent need for heightened awareness campaigns, particularly in areas with lower awareness, to educate individuals about the proper disposal and recycling of electronic waste. The pivotal role of government and local authorities in facilitating these educational efforts is evident. Moreover, a substantial number of respondents across various regions recognized

the significance of manufacturers incorporating recycling-friendly designs in their products. To effectively address the environmental challenges associated with EEE waste, it is imperative to adopt a more comprehensive, systematic, and region-specific approach. This approach should focus on public education, the enhancement of recycling infrastructure, and the promotion of responsible manufacturing practices. The insights gleaned from this survey provide a valuable resource for shaping future policies and initiatives aimed at improving WEEE management practices and reducing the environmental impact of electronic waste.

ACKNOWLEDGMENT

The authors are grateful to the staff of the Department of Environmental Technology, Sri Lanka Technological Campus (SLTC Research University), and those who took the time to respond to the questionnaire.

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2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

Importance of Nutritional Properties of Fruit and Vegetable Wastes and By-Products in Livestock Feed Production: A Review

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***Abstract*—In a world grappling with the dual challenges of food security and sustainable agricultural practices, the innovative use of fruit and vegetable processing by-product as livestock feed has emerged as a promising solution. Every year, vast quantities of fruits and vegetables are discarded due to cosmetic imperfections or surplus production, contributing to both food waste and environmental concerns. However, recognizing the nutritional value of this waste stream and its potential to enhance livestock diets presents an opportunity to simultaneously reduce waste, alleviate pressure on natural resources, and improve livestock productivity. This paradigm shifts towards utilizing fruit and vegetable waste as livestock feed not only demonstrates a commitment to waste reduction but also holds the potential to transform the way we think about sustainable food systems. Moreover, many studies showed that incorporation of fruit and vegetable wastes into livestock feed can effectively improve the livestock diet thereby productivity of a farm. This review article focuses on the utilization of fruit and vegetable processing by-products to livestock feed, their nutritional values, feeding management, and the constraints.**

Keywords*—*By-product, fruit, vegetable, livestock, feed

I INTRODUCTION

The livestock sector encompasses dairy, poultry, swine, goat, and sheep subsectors. In 2021, this livestock sector played a vital role, contributing approximately 11 percent to the country's agricultural GDP and providing employment for approximately 600,000 individuals [1]. In numerous developing Asian countries, there is a significant deficit in livestock feed availability, primarily attributable to constraints such as limited land for fodder cultivation, urban expansion, and competition among food, feed, and fuel resources [2]. Furthermore, the rising costs of feed ingredients have created a situation where cost-effective feed formulations are crucial. By incorporating less expensive alternatives, the overall cost of feed production can be reduced.

Fruit and vegetable processing by-products consists of wastage from the various stages of processing industries. Therefore, utilizing them as livestock feed presents an opportunity to address the prevalent feed shortage in many developing nations [3, 4] as wastage from fruit and vegetable processing are often available at low cost or even no cost. Incorporation of variety of fruits and vegetable wastes and by-products in feed formulation can create a more balanced diet for livestock. Fruits and vegetable by-products can be a valuable source of macro and micronutrients, phytochemicals such as carotenoids, phenolics, and flavonoids which possess antioxidant, antimicrobial properties [4]. Such positive functional and nutritional attributes can improve the palatability of the feed while contributing to better animal growth and health.

On the other hand, utilizing fruit and vegetable waste as livestock feed is a promising solution to address the challenges of food waste, environmental sustainability, and livestock productivity [5]. By repurposing these discarded resources, we can reduce food waste, minimize environmental impact, and enhance the efficiency of our agricultural practices. This innovative approach not only tackles pressing global issues but also paves the way for a more sustainable and responsible approach to food production and waste reduction.

Therefore, use of fruits and vegetable wastes and by-products in feed formulation for developing countries like Sri Lanka, is a sustainable and economically sound approach. Annual fruits and vegetable production in Sri Lanka exceeds 900, 000 MT (metric tons) [6]. Sri Lanka annually produces 710,000 MT of vegetables and 540,000 MT of fruits. About 40% of this production is wasted due to post-harvest loss. Additionally, 19% of vegetables (approximately 221,955 MT) and 21% of fruits (approximately 290,151 MT) are wasted during transportation [6], [7]. In Sri Lankan scenario, these resources remain largely unexplored, and their efficient utilization can expand the available feed supply, increase feed availability, and reintegrate wasted food into the human food supply chain [8].

The objective of this review is to explore the potential sources of fruit and vegetable wastes and by-products and summarize how their nutritional properties are beneficial in livestock feed formulation.

II FRUIT AND VEGETABLE WASTE AND BY-PRODUCTS AS LIVESTOCK FEED

The fruits and vegetables waste that was accessible included unprocessed fruits and vegetables that were not suitable for human consumption, as well as their peels, seeds, stones, and leftovers [1]. Numerous studies have explored the viability of using various fruit and vegetable wastes as livestock feed. Tables 1 and 2 provide a summary of select fruit and vegetable wastes and by-products including seeds, stalks, pulp, peels etc. which can be used in feed formulation. Use of these materials in feed formulation have been studied considering their suitability, chemical

composition, nutritional values, moisture content, contaminations such as microbes, pesticides, toxins etc.

TABLE I. STUDIED FRUIT WASTES AND BY-PRODUCTS THAT CAN BE USED AS LIVESTOCK FEED

Fruits	**Wastes and By-products**	**References**
Grapes	Pomace, Seeds, stalk	[40], [41],[42], [43]
Citrus fruits	Peel, Pulp, Ensiled Citrus pulp, Citrus molasses	[9], [10], [41], [42], [43]
Pomegranate	Seeds, Peel, Pulp	[43]
Apple	Peels, Core, Seeds, Stems	[41], [42], [43], [45]
Banana	Peels, Leaves, young stalks and Pseudo stems, Damaged banana	[3], [9], [42]
Muskmelon	Peels	[10]
Watermelon	Peels	[10]
Mango	Peels, Seed kernels	[9], [42]
Pineapple	Bran, Skin, Crown, Cannery waste, Pomace	[9], [42], [45]
Avocado	Peels	[42]

TABLE II. STUDIED VEGETABLE WASTES AND BY-PRODUCTS THAT CAN BE USED AS LIVESTOCK FEED

Vegetables	**Wastes and By-products**	**References**
Lettuce	Leaves	[3], [9], [23], [40]
Cabbage (red and green)	Leaves	[19], [21], [22], [23], [24], [26], [40], [42], [46]
Cauliflower	Leaves, inflorescence	[19], [20], [21], [22], [23], [24], [25], [40], [46]
Tomato	Pomace, Seed, Skin, Cull tomatoes	[41], [42], [43], [47]
Carrot	Peel, Pulp, Tops	[9], [10], [41], [43], [45], [48]
Soybean	Seeds	[41]
Potato	Peel	[40], [41], [42]
Sunflower	Seeds	[41]
Pumpkin	Peel, Pulp, Seeds, Seed flour	[28]
Pea	Empty pods	[9], [10]
Baby corn	Husk, Fodder	[9]
Bottle gourd	Pulp	[9]
Sugar beet	Leaves, Pulp	[9]
Radish	Leaves	[9]
Sweet potato	Whole or chopped cull sweet potato, Peels, Cannery waste	[44]

III NUTRITIONAL ATTRIBUTES OF FRUIT AND VEGETABLE BY-PRODUCTS THAT CONTRIBUTES TO THEIR UTILITY IN FEED FORMULATION

The characteristics of fruit and vegetable wastes and by-products such as nutrient density, diverse compositions, and cost effectiveness enable feed formulators to create nutritionally balanced, economically feasible, and environmentally friendly feeds for different animal species.

Nutrient density is a key contributing factor on the nutritional value of animal feed. Dried apple pomace which is a by-product left after apple have been processed is found to contain 7.7% crude protein (CP), 5.0% fat, and offers 1.86 Mcal metabolizable energy per kg of dry matter [9]. The same study has also shown that for lactating dairy cows, it provides 1.06 to1.12 Mcal net energy per kg of dry matter, with the best feed conversion observed at a 15% incorporation in their diet. Moreover, apple pomace can be valuable component in broiler rations as a partial replacement for maize [42] stated that in broiler rations, it can replace 10-20% of maize without negatively impacting broiler production [9].

Ripen banana peels contain approximately 8% crude protein, 6.2% fat, 13.8% soluble sugars, and 4.8% total phenolics [9, 10]. They are rich in trace elements, especially Fe, Cu, and Zn, surpassing safe intake levels for ruminants. Therefore, it is advisable not to feed banana peels ad libitum but to supplement them in the ruminant's diet as a source of organic minerals [9]. Several studies have suggested that in tropical areas, ripen banana peels can be utilized as an additional dietary resource for ruminant animals as it is readily available in many tropical areas being a cost-effective resource [9, 11, 12, 13]. Moreover, these studies have stated as banana peel contains significant amount of dietary fiber it is beneficial for ruminants which could be supporting proper microbial fermentation in the rumen.

Raw pineapple waste, on a dry matter basis, typically contains 4 to 8% crude protein, 60 to 72% neutral detergent fiber (NDF), and 40 to 75% soluble sugars which can contribute to the overall nutritional value of feed. However, it lacks minerals [9, 14, 15], necessitating supplementation with protein and minerals to prevent adverse effects on animal productivity and health [9].

Numerous studies have demonstrated that dried citrus pulp serves as a safe and effective alternative to cereals in the diets of animals on high-concentrate, low-roughage regimens, particularly high-yield dairy cows. Its nutrient content, fiber-rich nature, sustainability, and cost-effectiveness make it a feasible choice for livestock feed. It

can replace up to 20% of the concentrate in dairy cattle diets, up to 30% in lactating cow's diets, and up to 50% in gestating and lactating sow's diets [9]. Moreover, it can be included at levels of 20 to 30% in rabbit diets and 5 to10% in poultry diets [9]. When ensiled dried citrus pulp with wheat or rice straw in a 70:30 ratio, it produces excellent silage [9]. Importantly, these substitutions do not negatively impact essential factors such as dry matter intake, rumen metabolites, digestibility, milk production, or milk protein and fat content [9, 10, 16, 17, 18].

Numerous studies have consistently highlighted the potential of leafy vegetable waste materials as an excellent and cost-effective source of essential nutrients for livestock feed. For example, these studies consistently report a significant amount of crude protein (CP) in leafy vegetable waste, typically falling within the range of 14.4% to 24.1% [9, 19, 20, 21, 23]. The low-fat content of certain vegetable by-products provides a valuable option for feed formulators to control the overall fat content in animal feeds. Cabbage waste stands out for its relatively low levels of fat, which range from 0.5% to 2.3% [19, 22, 23]. This lower fat content is advantageous for ruminant diets, as high fat content can adversely affect rumen chemistry and biology [23]. Furthermore, research indicates varied levels of total ash content in different leafy vegetables. For example, the total ash content of cauliflower ranges from 7% to 16.7% [20, 21, 24, 25], cabbage from 2.3% to 17.2% [24, 26], and lettuce at 24.7% [23]. In addition, acid detergent fiber content (ADF), and NDF in vegetable by-products can offer several advantages in feed formulation especially for ruminants supporting digestive health. ADF is a measure of non-digestible components primarily composed of cellulose fibers and lignin [23] whereas NDF measures total fiber content consists of cellulose, hemicellulose, lignin, and other complex carbohydrates. Studies have reported ADF values for cabbage and cauliflower in the range of 22.9% to 23% and 20% to 29.3%, respectively [21, 22, 23, 24]. NDF is a crucial factor in animal diets, affecting both the amount of dry matter consumed by animals and the duration of their rumination. Moreover, NDF content in feeds is inversely related to their energy concentration [23]. For example, various studies have reported NDF values for cabbage ranging from 20.9% to 34%, while cauliflower had a NDF content of approximately 28% to 29% [19, 22, 23, 24]. These findings highlight the potential of utilizing leafy vegetable waste as a livestock feed, given its high crude protein content, low levels of fat, fiber, ADF, and NDF.

In a study by [9], fresh carrots were found to be rich in water (88%), crude protein (10%), and sugars, making them a valuable feed option for various animals. When incorporated into the diets of dairy cows, carrot by-products can enhance reproductive performance, including a reduced calving interval, fewer inseminations required for successful fertilization, and an increased calving rate and as carrots being a rich source of metabolizable energy (ME) , at 3.29 Mcal/kg DM and net energy (NE) , at 1.94 Mcal/kg DM can be fed at levels of up to 20 to 25 kg/day to lactating dairy cows and young bulls to a well body maintenance, growth, and lactation [8, 9]. Dehydrated carrots are popular as treats for laying hens; the addition of 4 to 8% dried carrot meal improves yolk color without affecting egg production. Carrot pomace, containing 64.3% soluble sugars, holds promise for providing nutritional value to animals [9]. A study conducted by [42] explored a variety of vegetable and fruit waste suitable for poultry diets. The findings indicate that culled carrots and carrot tops can enhance yolk color at inclusion levels of 4% and 15%, respectively.

Additionally, empty pea pods are also a valuable feed source for ruminants, owing to its high crude protein content (19.8%), soluble sugars, phenolics, and essential macro- and micro-elements. In addition, bottle gourd pulp waste can also be recommended at a level of 50% in the concentrate mixture for adult ruminants [9], [27].

The study done by [28] highlighted that research on the use of pumpkin seeds in animal feed such as for broiler chickens [29, 30, 31], laying hens [32, 33], turkeys [34], dairy cows [35], and pigs [36]. These studies have identified a range of bioactive compounds in pumpkin seeds and pulp, including antioxidants, antifungal, antiparasitic, antimicrobial, and anti-inflammatory substances. This suggests that the inclusion of pumpkin in animal diets has the potential to enhance the health, productivity, and overall well-being of livestock.

Fresh cull tomatoes which are removed during the packaging process due to damages are rich in protein (14 to 20% crude protein), fat (11 to13%), soluble sugars (90 to 95%), and pectin (5 to 10%) [9, 37, 38]. They can be fed to male goats alongside hay without digestive issues [9, 38]. Another study has shown that dried cull tomatoes can replace alfalfa meal for broilers as it contains 19 to 22% crude protein and 11 to 13% fat) [9]. Further, ground tomato pomace can fully replace concentrates in the diet of male buffaloes without affecting feed intake, nutrient digestibility, or rumen function, as shown in multiple studies [9, 39]. Dried tomato pomace (20%) and tomato seed (15%) are suitable additions, while cooked potatoes and sweet potato meal (up to 40%) and peeled sweet potatoes (up to 15%) are viable options [42].

In a 2012 study conducted by (40), an analysis of fruit and vegetable waste from a Colombian marketplace has been performed, focusing on nutritional aspects. The study revealed that FV contained approximately 10% CP, 36.6% NDF, and 29.6% ADF. Moreover, it exhibited high ruminal degradability at 87.8% within 24 hours, possessed an energy content of 3657 kcal/kg, and contained 0.59% calcium (Ca^{2+}) and 0.21% phosphorus (P). These findings strongly highlight the potential of FV as a promising feed option for bovine nutrition.

Utilizing waste from the fruit and vegetable processing industry in formulating animal feed can be a successful practice for a variety of farm animals, including poultry, ruminants, and non-ruminants. Incorporating these by-products into animal diets can lead to significant improvements in animal growth, performance, reproduction, and the quality of products such as meat, milk, and eggs. These improvements are attributed to the antioxidant and antimicrobial properties of the ingredients, positive changes in fatty acid composition, enhanced yolk color, and improved milk fatty acid composition. Furthermore, peels, pomace, and seeds are potent reservoirs of bioactive compounds, including flavonoids, tannins, polyphenols, and antioxidants. These compounds not only modulate ruminal processes but also exert positive effects on ruminant health, bolstering immune systems and enhancing milk production [21, 43]. Importantly, it has been observed that the inclusion of fruit and vegetable by-products/wastes in livestock diets

does not have any adverse effects on animal performance. Therefore, as the review summarized, fruit and vegetable by-products can be considered as a sustainable alternative to conventional animal feed. Nevertheless, it is essential to handle feed formulation carefully to promote both sustainable animal production and improved nutrition.

IV Challenges

The utilization of fruit and vegetable waste as feed for livestock poses several obstacles. One major challenge is the perishable nature of these waste materials. Fruits and vegetables can quickly spoil [49], which makes it difficult to store and use them as consistent feed sources for livestock. Additionally, there is the issue of heterogeneity [49], meaning that these by-products can vary in composition and quality, making it challenging to provide a uniform and balanced diet for the animals.

The next dominant challenges associated with using these products as livestock feed are elevated moisture levels and the presence of contaminants, predominantly pesticides and their residues. It is imperative to establish a monitoring system for assessing the levels of pesticides, pesticide residues, mycotoxins, heavy metals, and antinutritional factors before incorporating vegetable products into animal diets [3, 8]. This precautionary step is crucial to ensure the safety and nutritional quality of the feed and, consequently, the health and productivity of the livestock. Supporting this report by [51] highlighted that, collecting and storing fruit and vegetable waste for livestock feed face challenges due to the diverse sources, seasonal variability, perishability, space constraints, and the need for hygiene and contamination control.

To encourage food-waste producers and the livestock industry to actively promote and implement change, it will be essential to establish legislation rooted in scientifically sound research. This legislation can serve as a powerful incentive, providing a structured framework for reducing food waste and optimizing the use of waste materials as livestock feed [50]. By ensuring that these regulations are well-informed by rigorous research, they can effectively drive the necessary changes in both sectors, fostering more sustainable practices and reducing overall waste in the food supply chain.

V Conclusion

In summary, this review highlights the significant potential of fruit and vegetable wastes and by-products as a sustainable resource in livestock feed. It emphasizes the importance of nutritional value and sound feeding management, revealing the role of fruit and vegetable by-products in promoting economic and ecological sustainability in the livestock industry. While using these waste materials helps reduce food waste and enhances animal nutrition and herd health, it must be cautious about any possible toxic chemicals, heavy metals, and pesticide residues in fruit and vegetable by-products. Therefore, careful assessment and handling of these materials are vital. By addressing these concerns, benefits of fruits and vegetable by-products can be enhanced while minimizing potential risks and continue working toward a more responsible and sustainable future in livestock production.

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2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

Assessment of Plant Species in Colombo District in Sri Lanka as an Air Pollution Mitigation Measure

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***Abstract*—Human-induced changes in air composition pose significant threats to both organisms and the environment, emphasizing the urgent need for the adoption of effective nature-based solutions to mitigate these challenges. This study aimed to assess the effectiveness of plants in mitigating air pollution, ultimately identifying tree species suitable for urban forest development by comparing the Air Pollution Tolerance Index (APTI) and Anticipated Performance Index (API) of six tree species: *Azadirachta indica, Cassia fistula, Filicium decipiens, Macaranga peltata, Mangifera indica,* and *Terminalia catappa,* all of which are found in the Colombo District, Sri Lanka. The study was conducted in two distinct environmental settings, one classified as least air polluted (located in Padukka) and the other as highly air polluted (situated in Maharagama). Ten individual trees were chosen from each species at every study site, and these trees were treated as replicates for each species. Socio-economic parameters of selected plant species based on a literature survey were used for the study. The study revealed significant variations ($p<0.05$) in biochemical parameters including ascorbic acid content, total chlorophyll content, leaf extract pH, relative water content, and APTI among various tree species and locations. Notably, the highest APTI values were observed in *M. peltata* at both the least polluted (13.35±0.80) and highly polluted (12.17±0.71) sites. The API values indicate that *M. indica* is highly suitable for urban planting ('Very good'), *A. indica* and *M. peltata* are 'good' choices, *F. decipiens* and *T. catappa* are 'moderate', while *C. fistula* is 'poor' in their suitability as tree species for urban landscapes.**

***Keywords*—Air pollution, urban planning, air pollution tolerance index, anticipated performance index, biomonitoring**

I. INTRODUCTION

In recent decades, urban areas have witnessed a growing environmental strain, with communities worldwide grappling with crises, predominantly stemming from deteriorating air quality. The primary factors contributing to this issue include the continual expansion of the population, the inappropriate land utilization relative to the population's needs, the congestion triggered by the rising volume of vehicles, and the subsequent escalation in the concentration of harmful gases in the atmosphere. In light of these challenges, the global spotlight has shifted towards green infrastructure, with a particular emphasis on urban forests. Urban forests encompass the collective expanse of trees and shrubbery within city limits, encompassing trees in residential yards, along streets, and within utility corridors, as well as safeguarded natural areas and watersheds. This includes individual trees, street-side plantings, green spaces adorned with trees and their associated vegetation, and even the soil beneath these trees. Presently, a prevailing trend involves the creation of urban forests, urban forest parks, green belts, and green corridors to mitigate the prospective impacts of air pollution, global warming, and climate change. Air pollution affects both plants and humans, with plants undergoing physiological transformations even before observable damage to their leaves occurs. When exposed to airborne pollutants, plants undergo these physiological shifts prior to displaying visible leaf damage. Given that trees play a vital role in their routine functions by removing a substantial amount of pollutants from the environment, they significantly enhance air quality and should thus be deemed an essential component in the broader effort to improve overall air quality [7].

Comprehending the factors that impact sensitivity and tolerance can enhance the understanding of how plants react to pollutants on physiological and biochemical levels. A method

was presented, utilizing four biochemical parameters, ascorbic acid, total chlorophyll content, leaf extract pH, and relative water content to evaluate the susceptibility and tolerance of plants to air pollution [12]. This method yields the Air Pollution Tolerance Index (APTI), which characterizes the innate ability of plants to withstand air pollution. The APTI index provides valuable insights into the impact of pollutants, focusing exclusively on biochemical parameters. Nevertheless, the Anticipated Performance Index (API), designed to mitigate air pollution through the promotion of urban forests and green belts, takes into consideration additional socioeconomic and biological factors [11]. API calculations can also determine which plant species are most suitable for environmental management [5], and API proves especially valuable in identifying plant species capable of fulfilling the dual role of enhancing air quality through the removal of atmospheric pollutants and providing recreational benefits [4].

This study aimed to investigate the air pollution tolerance of plant species in the context of establishing urban forests to mitigate air pollution in urban environments. To achieve this, the study encompasses the analysis of various biological and socio-economic parameters and the assessment of the APTI and the API for a specific group of plants in various locations with diverse air pollution profiles. The ultimate goal is to provide practical recommendations to improve air pollution tolerance and the overall performance of plant species in urban forests, thereby contributing to the development of sustainable green spaces that improve not only air quality but also the health and well-being of urban residents. The majority of research on the air pollution tolerance of urban plant species has predominantly concentrated on species located along roadsides, typically utilizing the APTI. However, this study delves into both the APTI and the API to evaluate the tolerance of urban trees to air pollution. Its aim is to pinpoint the most appropriate tree species for the development of urban forests as a strategy to alleviate air pollution.

II. Materials and Methods

A. Experimental Sites

This study was conducted in the Colombo district of Sri Lanka, a tropical island situated to the south of the Indian subcontinent. The selection of study sites in Colombo was based on the ambient air levels of SO_2, NO_2, PM2.5, and PM10, categorizing them into two distinct categories: "control site" (CS) and "polluted site" (PS). Consequently, the premises of Sri Lanka Technological Campus (SLTC Research University) were designated as the control site, while Maharagama was identified as the polluted site. In the selection of study sites, the control site was primarily selected systematically. Polluted sites were then selected based on precise analysis of air quality data, facilitating a comprehensive comparison with the control site. Sri Lanka Technological Campus, located in the biodiverse region of Padukka, was chosen as the control site for sampling due to its remote location, away from the city. The average ambient air levels of SO_2, NO_2, PM2.5, and PM10 around the area were recorded as 11 $\mu g/m^3$, 4 $\mu g/m^3$, 22 $\mu g/m^3$, and 30 $\mu g/m^3$, respectively [2]. In contrast, Maharagama is a city characterized by rapid housing development and urbanization and is renowned for having some of the highest air pollution levels, largely attributable to heavy traffic. In Maharagama, the average ambient air levels of SO_2, NO_2, PM2.5, and PM10 around the area were measured at 24 $\mu g/m^3$, 15 $\mu g/m^3$, 60 $\mu g/m^3$, and 43 $\mu g/m^3$, respectively [2], thus making it a suitable site for sampling. It's worth noting that the soil condition was consistent across all the studied zones.

B. Sample Collection

A preliminary field study was carried out to collect data regarding a variety of urban trees and their locations because there are no existing records of their locations or species. Plant species were selected considering the study of the abundance of plant species in the selected areas and being indigenous/ native species. Selected plant species (Fig. 1) were *Azadirachta indica* (Neem tree), *Cassia fistula L.* (Golden shower tree), *Filicium decipiens* (Fern tree), *Macaranga peltata* (Chandada or Kenda tree), *Mangifera zeylanica* (Mango tree), and *Terminalia catappa L.* (Indian almond tree).

Fig. 1. Selected plant species for analysis

Ten individual trees were selected from each species at every study site, and these trees were considered replicates for each respective species. All chosen tree specimens were within the age range of 5 to 10 years. Given the absence of documented records regarding the trees' ages or planting years, we relied on oral accounts provided by neighboring residents of the study sites to estimate the trees' ages, thereby integrating this qualitative data into this study. Mature leaves from chosen individuals of each species were randomly gathered in the morning, specifically between 7:00 am and 9:00 am, to minimize exposure to dust and other potential obstacles. This timing is crucial to obtain the fresh weight of the leaves. Leaf samples were obtained from the lowermost part of the canopy, approximately at a height of 1.8 to 2 meters above the ground surface. Sampling was conducted during August and September, coinciding with the southwest monsoon season (also known as the wet season). The collected samples were meticulously sealed in individual polythene bags and transported to the laboratory. Upon reaching the laboratory, the fresh weight of the leaves was documented, and the samples were then stored at 4 °C. To facilitate further analysis, a composite leaf sample was generated from each individual.

C. Biochemical Analysis

Laboratory analysis was performed to evaluate the Air Pollution Tolerance Index (APTI) by examining four crucial biochemical parameters: Ascorbic Acid Content (AAC), Relative Water Content (RWC), Total Chlorophyll Content (TChC), and pH. The measurement of AAC was carried out using the spectrophotometric method [3]. A fresh leaf sample weighing one gram was extracted using a solution comprising Oxalic acid – EDTA (4 mL), orthophosphoric acid (1 mL), 5% (v/v) sulfuric acid (1 mL), 5% (m/v) ammonium molybdate (2 mL), and water (3 mL). Following a 15-minute incubation period, the absorbance of the solution was measured at 520 nm and 760 nm using a UV-visible spectrophotometer. The concentration of ascorbic acid in the sample was extrapolated from a standard ascorbic curve, and the results were duly recorded. The gravimetric method was employed to ascertain the RWC of the leaves [9]. A quantity of 30 grams of fresh leaves was acquired from each sample as the initial fresh weight. These leaves were immersed in water overnight, subsequently dried and weighed to establish the turgid weight. Following this, the leaves were subjected to drying in an oven at 70 °C for a day, and the resulting weight provided the dry weight. Equation (1) was applied in the calculation process.

$$RWC = \frac{(FW - DW)}{(TW - DW)} \times 100 \qquad (1)$$

Where, RWC = Relative Water Content (%), FW = Fresh Weight (g), DW = Dry Weight (g), and TW = Turgid Weight (g)

The determination of TChC followed the spectrophotometric method outlined by [3]. Three grams of fresh leaves were blended and extracted with 10 mL of 80% acetone, followed by a 15-minute incubation period. The liquid portion underwent decantation and centrifugation at 2500 rpm for 3 minutes. The resulting supernatant was collected, and the absorbance at 645 nm and 663 nm was recorded. Equations (2), (3), and (4) were applied for subsequent calculations.

$$Chlorophyll\ a = \frac{12.7Dx_{663} - 2.69Dx_{645} \times V}{1000W}(mg/g) \qquad (2)$$

$$Chlorophyll\ b = \frac{22.9Dx_{645} - 4.68Dx_{663} \times V}{1000W}(mg/g) \qquad (3)$$

$$TChC = Chlorophyll\ a + Chlorophyll\ b\ (mg/g) \qquad (4)$$

Where, D_x= Absorbance of the extract at the wavelength X nm, V = Total volume of the chlorophyll solution (mL), W = Weight of the tissue extract (g), Leaf extract pH

The pH of leaf extracts was determined by homogenizing 5 grams of leaf samples with 50 mL of deionized water, and the resulting leaf extract's pH was measured using a pH meter calibrated with pH 4 and 9 buffer solutions. Carbonic acid and sodium bicarbonate served as the buffer solutions [3, 9].

D. Socio-Economic Parameters

Traditional criteria for choosing plants for urban vegetation usually concentrate on a limited set of observable characteristics, including color, shedding, shape, size, plant habit, leaf structure, and canopy structure. The most dependable sources of information include a review of published literature and several official websites that were consulted to identify relevant socio-economic parameters of the selected plant species [4].

E. APTI and API Determination

APTI only gives the effect of pollutants on biochemical parameters. This expresses the ability of a plant to fight air pollution. APTI was calculated using the following equation (5) [3].

$$APTI = \frac{A(P + T) + R}{10} \qquad (5)$$

Where; A = Ascorbic Acid (mg/g), T = Total Chlorophyll (mg/g), P = Leaf Extract pH, R = Relative Water Content (%), APTI = Air Pollution Tolerance Index

Tab. 1 [3] provides the categorization of APTI results for various plants into different tolerance levels. Plants exhibiting higher APTI values demonstrate greater tolerance to air pollution, whereas those with lower APTI values indicate lower tolerance.

TABLE 1. CLASSIFICATION OF APTI VALUES IN TREE SPECIES INTO DISTINCT TOLERANCE LEVELS

Range of APTI	**Tolerance Level**
a) Tree species with APTI higher than mean APTI+SD	Tolerant
b) Tree species with APTI value between mean APTI and mean APTI+SD	Moderately Tolerant
c) Tree species with APTI value between mean APTI-SD and mean APTI	Intermediate
d) Tree species with APTI lower than mean APTI+SD	Sensitive

As described by [4] the key criteria and corresponding grades for API determination using plus (+) and minus (-) marks. The key criteria are APTI, plant habitat, canopy structure, plant type, size, texture, and hardiness of the lamina and economic value of the species. Assessment of API was done using equation 5 after obtaining the total score. There are eight grades from 0 to 7, indicating plants unsuitable for urban forest development to excellent plants. An API value below 50% is a poor and not recommended plants and above 50% varies from moderate to excellent plants with good API score.

$$API = \frac{No\ of\ '+'obtained}{16} \times 100 \qquad (6)$$

F. Statistical Analysis

The study utilized a two-sample t-test to assess the significance of variations in selected biochemical parameters and the resulting APTI values for each species between the sites with the lowest and highest pollution levels. Additionally, a standard one-way analysis of variance (ANOVA) was performed to examine the significance of differences in APTI values among the six chosen urban tree species at each site.

III. Results and Discussion

A. Biochemical Parameters and APTI Comparison

The resistivity and susceptibility of tree species are predominantly influenced by the biochemical parameters investigated for APTI. Tab. 2 displays the biochemical result of calculating the APTI for six tree species growing in polluted and control sites. Based on the mean RWC results, in the control site, *M. peltata* exhibited a significantly higher relative water content at 93.70±0.01%, whereas *C. fistula* recorded the lowest value at 84.05±0.03%. In the polluted site, *F. decipiens* displayed a significantly higher relative water content at 89.63±0.03%, while *T. catappa* registered the lowest value at 71.92±0.03%. A plant's ability to withstand and maintain its physiological balance under stressful conditions, including drought, is improved when it has a higher relative water content in its tissues [4].

Table 2. Assessment of Air Pollution Tolerance Index (Results are Presented as Mean ± SEM (N =10)

Species	**Site**	**RWC (%)**	**TChC (**mg/g)	**AAC (**mg/g)	**pH**	**APTI**
A. indica	CS	86.26 ±0.03	0.24 ± 0.04	4.75 ±0.32	6.70 ±0.38	12.80 ±0.31
	PS	82.95 ±0.05	0.22 ± 0.04	6.22 ±0.33	6.44 ±0.12	11.42 ±0.59
C. fistula	CS	84.05 ±0.03	0.34 ± 0.03	6.14 ±0.48	6.74 ±0.51	12.14 ±0.50
	PS	82.24 ±0.03	0.34 ± 0.02	2.58 ±0.76	5.76 ±0.44	10.06 ±0.66
F. decipiens	CS	90.82 ±0.03	0.23 ± 0.03	4.28 ±0.57	6.66 ±0.41	11.94 ±0.68
	PS	89.63 ±0.03	0.23 ±0.03	3.20 ±0.66	6.35 ±0.44	11.18 ±0.77
M. peltata	CS	93.70 ±0.01	0.37 ±0.03	5.39 ±0.52	5.71 ±0.33	13.35 ±0.80
	PS	83.40 ±0.02	0.36 ±0.03	8.12 ±1.94	4.58 ±0.31	12.17 ±0.71
M. indica	CS	85.75 ±0.03	0.35 ±0.05	5.43 ±0.32	5.72 ±0.53	11.69 ±0.41
	PS	79.30 ±0.04	0.36 ±0.06	4.41 ±0.26	5.38 ±0.30	10.62 ±0.52
T. catappa	CS	85.38 ±0.07	0.29 ±0.04	7.52 ±0.39	4.98 ±0.48	12.16 ±0.49
	PS	71.92 ±0.03	0.28 ±0.04	6.20 ±0.65	4.52 ±0.24	10.44 ±0.50

TChC in plants significantly influences photosynthetic activity and biomass growth [2]. At the control site, *M. peltata* exhibited a significantly higher TChC at 0.37±0.03 mg/g, whereas *F. decipiens* registered the lowest value at 0.23±0.03 mg/g. In the polluted site, *M. peltata* and *M. indica* (0.36±0.03 mg/g and 0.36±0.06) recorded significantly higher TChC, while *A. indica* (0.22±0.04 mg/g) recorded the lowest value. It can be triggered by the deposition of dust on the leaf surface and exposure to air pollution [7]. Tolerant plants make an effort to maintain higher TChC as a defense mechanism against air pollution. This is supported by the observation that *M. peltata*, which demonstrated the highest TChC in the control site, is documented as being tolerant according to its APTI. As an antioxidant, AAC plays a pivotal role in shaping the resilience of plants against adverse environmental factors, especially air pollution [4]. In the control site, *T. catappa* (7.52±0.39 mg/g) recorded significantly higher AAC while *F. decipiens* (4.28±0.57 mg/g) recorded the lowest value. In the Polluted site, *M. peltata* (8.12±1.94 mg/g) recorded significantly higher AAC while *C. fistula* (2.58±0.76 mg/g) recorded the lowest value. A defensive system of plants in an environment is favored by a high concentration of ascorbic acid [3]. The pH acts as an indicator of sensitivity to air pollution. In the control site, *C. fistula* (6.74±0.51), *A. indica* (6.70±0.38), and *F. decipiens* (6.66±0.41) recorded significantly higher pH while *T. catappa* (4.98 ± 0.48) recorded the lowest value. In the polluted site, *A. indica* (6.44±0.12) recorded significantly higher pH value while *T. catappa* (4.52±0.24) recorded the lowest value. All the leaf extracts of the plant species collected from the polluted site were observed to be more acidic than the control site. According to [3, 1]. the acidic pH observed in leaf extracts of tree species is likely attributed to high levels of SO_2 and NO_2 in the ambient air.

For each of the six selected tree species, a decrease in APTI was observed at the polluted location compared to the control site. This decline is evident from the reduction in all biochemical parameters when moving from the least to the polluted site. In the control site, *M. peltata* (13.35±0.80) recorded significantly higher APTI value while *M. indica* (11.69±0.41) recorded the lowest value. In the polluted site, *M. peltata* (12.17±0.71) recorded a significantly higher APTI value while *C. fistula* (10.06±0.66) recorded the lowest value.

TABLE 3. TREE SPECIES CATEGORIZATION INTO DISTINCT TOLERANCE LEVELS BASED ON APTI VALUES

Species	Site	APTI	Mean APTI	Category
A. indica	CS	12.80	11.74	Tolerant
	PS	11.42	10.98	M. Tolerant
C. fistula	CS	12.14	11.74	M. Tolerant
	PS	10.06	10.98	Intermediate
F. decipiens	CS	11.94	11.74	M. Tolerant
	PS	11.18	10.98	M. Tolerant
M. peltata	CS	13.35	11.74	Tolerant
	PS	12.17	10.98	Tolerant
M. indica	CS	11.69	11.74	Intermediate
	PS	10.62	10.98	Intermediate
T. catappa	CS	12.16	11.74	M. Tolerant
	PS	10.44	10.98	Intermediate

Tab. 3 illustrates the classification of tree species into different tolerance levels, determined by their APTI values and standard deviation (SD). The SD value for the polluted site and the control site was 0.93 and 0.61 respectively. The tolerance category of each species was different in the two sites. *A. indica* and *M. peltata* were categorized as tolerant species in the control site while in the moderately tolerant category in the polluted site. *C. fistula* and *T. catappa* are in the moderately tolerant category in the control site and in the polluted site are classified as intermediately tolerant species. The tolerance of *F. decipiens* is categorized as moderately tolerant in both sites. The tolerance category of *M. indica* remains unchanged in both sites and categorized as an intermediate species.

The statistical analysis identified a significant difference ($p < 0.05$) in APTI values among the six chosen urban tree species at each site. Based on an ANOVA performed, there was no significant difference between the RWC of the test species at both sites. There was a significant difference in the AAC in all plants at both sites. This implies that a plant's ability to withstand air pollution differs depending on its site. With the exception of *M. peltata*, all plant species showed significant differences in pH. A significant difference in TChC was found for *M. indica* species. In terms of APTI values, *C. fistula*, and *T.catappa* were statistically significant. It can be said that those species have the adaptability to combat stress under different environmental conditions.

B. Assessment of API

Tab. 4 summarizes API of different plant species. It reveals that *M. indica* performed as 'very good' for urban forest developments. According to the grading of two sites *T. catappa*, *A. indica*, and *M. peltata* performed as 'good' plant species and *F. decipiens* is a 'moderate' performer. *C. fistula* is recorded as a 'poor' performer in order to urban forest development. According to the findings of this study, certain plants, such as *M. indica, F. decipiens, and T. catappa*, exhibit low APTI values while demonstrating excellent API. This could be ascribed to advantageous socio-economic factors that boost the phytoremediation capabilities of these plants. Moreover, these species possess significant economic and aesthetic value [4]. It was followed by the maximum API of *A. indica* and *M. peltata* may be due to its high APTI. API value is more for the species with higher APTI having better plant and leaf characteristics[6].

TABLE 4. ASSESSMENT OF ANTICIPATED PERFORMANCE INDEX

Species	Grade Allocated		API Grade	API Assessment
	Total Plus	Percentage		
A. indica	9	56	4	Good
C. fistula	8	50	2	Poor
F. decipiens	11	69	4	Good
M. peltata	11	69	4	Good
M. indica	12	75	5	Very Good
T. catappa	10	63	4	Good

A thorough examination of the findings indicates diverse responses among different plant species to air pollution. Furthermore, the study underscores the influence of air pollution on crucial factors such as total chlorophyll content, ascorbic acid content, relative water content, and leaf extract pH. Plants exhibiting lower index values indicate diminished tolerance and can function as indicators of the degree of air pollution [12]. On the other hand, higher Air Pollution Tolerance Index values are indicative of plant species' resilience to air pollutants [8]. It is crucial to emphasize that a plant's capacity to withstand air pollutants is contingent on the specific site conditions, including the nature and concentration of the pollution [10].

IV. CONCLUSION

A consistent pattern of declining APTI values was observed from the polluted site to the control site for all chosen tree species. In terms of air pollution tolerance, *Macaranga peltata* stood out as the most resilient tree species in both sites. Plants characterized by low APTI index values exhibit low tolerance, while those with high APTI values demonstrate a high tolerance to air pollutants. The capability of plants to withstand air pollutants is specific to the site and relies on the type and concentration of pollution. The API scores indicated that among the tested tree species, *Mangifera indica* was categorized as 'very good' in terms of suitability for planting in urban forests due to its highest API score. Based on the outcomes obtained through the API assessment, it is recommended that all plant species, except for *Cassia fistula*, exhibit suitability for urban environments. Certain species demonstrate the highest APTI grades, while in other cases, factors like canopy structure and economic value also play a role. APTI and API have gained broad acceptance as reliable methods for assessing plant tolerance to air pollution. They are

valuable tools for designing urban forests and landscapes that are visually appealing and environmentally sustainable. Future studies should delve into the tolerance of additional tree species to urban environments characterized by air pollution. Furthermore, considering the relevant parameters for these trees across various age groups and over extended periods, during both wet and dry seasons, would be valuable for evaluating crop productivity in the face of air pollution across different seasons.

ACKNOWLEDGEMENT

This investigation received financial support from the Research and Development Funds of Sri Lanka Technological Campus. The authors are very much grateful to staff members of the Department of Environmental Technology and Department of Biosystems Engineering of Sri Lanka Technological Campus for their assistance during the study period.

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2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

Meta-Analysis of Microbial Communities Reveals The Insights into the Ecological Roles of Microbiota in Wastewater Treatment Plants

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***Abstract*—The wastewater treatment process is a complex undertaking with the primary objective of eliminating contaminants and rendering the water suitable for discharge into natural water bodies or for alternative purposes. It holds significant importance in safeguarding public health and preserving the environment. Within this process, microorganisms including bacteria, fungi, and protozoa assume a pivotal role by de-composing organic pollutants and transforming them into harmless by-products. Bioreactors offer an optimal environment for the proliferation and activity of these microorganisms, which are cultivated in large quantities to effectively consume organic substances in the wastewater, thereby reducing pollutant levels. In the secondary treatment stage, microorganisms are also employed to eliminate any remaining pollutants further. Biological wastewater treatment stands as one of the most crucial applications of biotechnology. Wastewater treatment facilities play a vital role in preventing the contamination of natural ecosystems. Traditional mathematical models used in the de-sign of wastewater treatment plants (WWTPs) face limitations in accurately capturing the complex metabolic activities within bacterial cells. However, advancements in sequencing technologies and computation-al capabilities have enabled us to explore the taxonomic and function-al identification of microorganisms present in WWTPs. Furthermore, adopting a systems biology approach offers a comprehensive under-standing of the ecological interactions among microbial communities and their consequential impact on process efficiency. Understanding the ecological dynamics of microbial communities in WWTPs is crucial for unravelling the intricate nutrient transformation processes. Conventional wastewater treatment models often neglect this ecological aspect, but integrating ecological insights into these models, although challenging, is essential for better WWTP design and optimization. Addressing key research questions, such as identifying the members of microbial communities and their roles, is paramount for incorporating ecological insights into WWTP design. By employing meta-analysis, this study uncovers the central microbial components and their interrelationships, providing valuable insights into the factors that influence process dynamics.**

Keywords—Wastewater, microbial, community, bioinformatics, bacteria

I. INTRODUCTION

The wastewater treatment process is a complex undertaking with the primary objective of eliminating contaminants and rendering the water suitable for discharge into natural water bodies or for alternative purposes [1]. It holds significant importance in safeguarding public health and preserving the environment. Within this process, microorganisms including bacteria, fungi, and protozoa assume a pivotal role by decomposing organic pollutants and transforming them into harmless byproducts [2]. Bioreactors offer an optimal environment for the proliferation and activity of these microorganisms, which are cultivated in large quantities to effectively consume organic substances in the wastewater, thereby reducing pollutant levels. In the secondary treatment stage, microorganisms are also employed to further eliminate any remaining pollutants. Biological wastewater treatment stands as one of the most crucial applications of biotechnology. Wastewater treatment facilities play a vital role in preventing the contamination of natural ecosystems and the proliferation of diseases transmitted through sewage, such as cholera and typhoid fever.

A significant number of studies have been done in different wastewater systems, however, most of the studies have been done based on samples taken from individual applications. Only a limited number of studies have been done covering a wide range of applications, analyzing how microbial communities in a wide range can correlate.

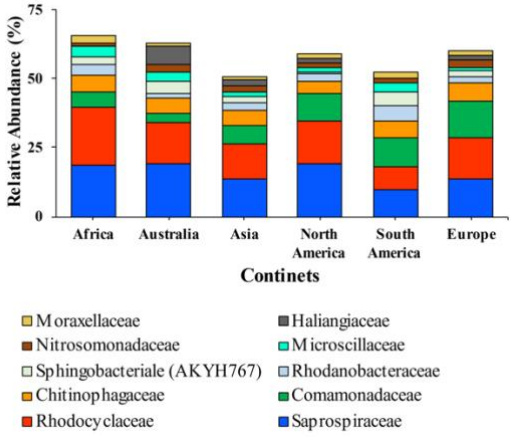

Fig. 1. Relative abundance of most abundant families by continents

The present study endeavors to undertake a meta-analysis of microbial communities encompassing diverse municipal wastewater treatment plants situated in various geographical regions. To achieve this objective, a meticulous examination of publicly accessible data was conducted via comprehensive

metagenomic analysis. Multiple datasets comprising samples from water treatment systems were carefully chosen from the study on municipal WWTPs, and subsequently subjected to analysis utilizing bioinformatic tools. Network analysis, a widely employed data analysis technique, was employed to elucidate taxa that share common ecological roles within the investigated ecosystems [3]. This method has proven to be highly effective in analyzing intricate systems characterized by complex interactions and inferring community structures.

Accordingly, both network analysis and statistical analysis will be executed to discern the identities of microorganisms present and explore their correlations.

II. Materials and Methods

A. Bioinformatic Work Flow for the Publicly Available Data

16S rRNA amplicon sequencing datasets from various wastewater sources, obtained from the European Nucleotide Archive [4]. Usegalaxy.org server was used to run the bioinformatic pipe line to analyze the sequencing data retrieved from the selected studies [5].

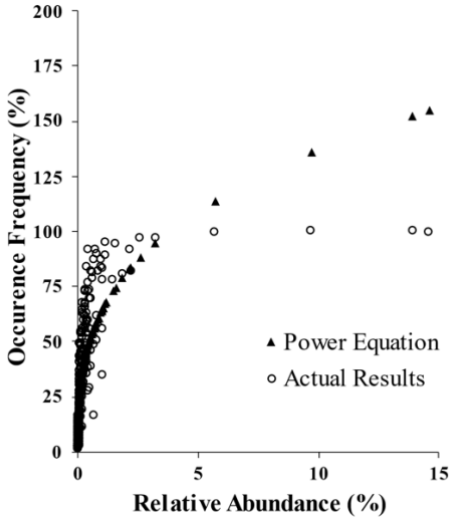

Fig. 2. Occurrence frequency vas Relative abundance actual results and predicted values using power equation

A total of 116 samples from municipal wastewater treatment plants across 6 continents were selected which included 5,536,897 reads (Study: PRJNA509305). The DADA2 genomic data analysis pipeline was used for this analysis [6]. The Filter and Trim step removed low-quality reads, adapter sequences, and contaminants to ensure data accuracy (Truncate read length = 0, minimum read length = 20, and a maximum expected error per read = 2). The plot quality profile function visualized the quality scores across all reads, while the Learn errors function estimated the error model without the need for a reference genome. *Remove Bimera Denovo* step identified and removed chimeric sequences which reduced the screened Amplicon Sequence Variants (ASV) from 80,138 to 39,251. The sequence count provides valuable information about the biological diversity and abundance in the samples. Taxonomic classification of amplicon sequence variants was performed using the *SILVA NR99* database [7].

B. Community Analysis and Mathamatical Modelling

ASV data was sorted to obtain relative abundance, average abundance, abundance frequency, and key microorganisms of the samples. Then, the communities were analyzed through clustering using the PAST software [8], which performs a principal component analysis (PCA). Three models (Nachman, Hanski-Gyllenberg, Power,) [9] were used to describe the quantitative relationship between the observed occurrence frequency and relative abundance of ASVs across the selected samples.

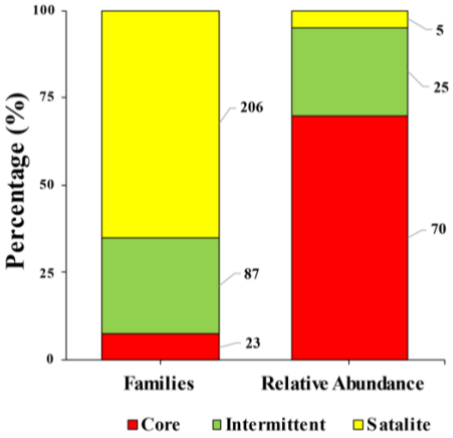

Fig. 3. Average relative abundance of three groups: core, intermittent, and transient groups based on occurrence frequency (%)

C. Network Analysis

The connectedness of microorganisms families were identified by developing a co-occurrence network using Cytoscape® [10] software. R software was used to analyze the relative abundance data of the bacterial families. Statistical significance was tested using *cor.test()* function and screening the correlation with P Value < 0.05. Screened nodes (representing the average relative abundance of families) were then represented with edges (representing Pearson's correlation).

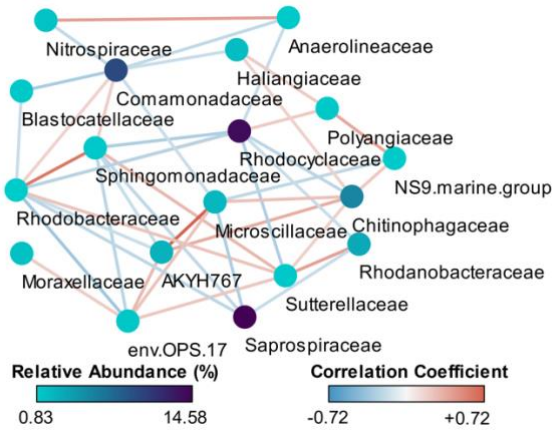

Fig. 4. Network diagram for the bacterial communities representing the association between bacterial families

III. Results

A. Community Analysis and Mathamatical Modelling

A total of 316 bacterial families were identified among the 116 samples obtained from municipal wastewater

treatment plants. Figure 1 shows the number of families and their relative abundance. Among these families, a subset of 23 families accounted for a cumulative relative abundance of 70%. This indicates that these 23 families collectively contribute significantly to the overall microbial composition, representing most of the microbial community in the samples. Furthermore, an additional 87 families collectively accounted for 24.99% of the cumulative relative abundance. These families, while less abundant compared to the top 23 families, still contribute substantially to the overall microbial community composition. It is worth noting that the remaining 206 families, which were not included in the top 23 or 87 families, collectively accounted for 4.72% of the cumulative relative abundance.

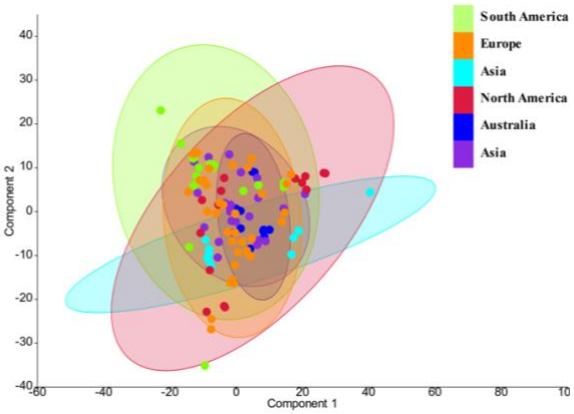

Fig. 5. PCA of all samples. 95% confidence intervals are indicated by shaded area grouping each continent

Although individually less abundant, these families play a role in the overall diversity and composition of the microbial communities in wastewater treatment plants. This distribution of cumulative relative abundance highlights the presence of both dominant and less abundant microbial families in the samples. The dominance of the top 23 families, collectively accounting for 70% of the abundance, (Figure 3) underscores their potential functional importance and influence on the overall microbial community dynamics in wastewater treatment plants. From the one way ANOSIM using PAST[8] it was identified that the communities in South America was significantly different from Asia and Europe samples (Bonfferoni corrected *P* value < 0.05) [11].

From the mathematical equations used to model the relationship between the prevalence (Occurrence) and abundance, Power equation was fitted with *P* Value = 0.01 and root sum square (rss) = 59150.11 (Figure 2).

$$P = \frac{\alpha\beta^{\mu}}{1 + \alpha\beta^{\mu}}$$

μ and *P* represent the relative abundance and occurrence frequency, respectively. Fitted values for the model were α=64.45, β=0.33.

B. *Network Analysis*

Family level association network (Figure 4) consists of 18 nodes and 41 edges. Each node representing a bacterial family was associated with another bacterial family with an average association of 4.56. The network diameter (number of consecutive edges for longest distance) was 3. No self-loops or multi-edge node pairs are identified in this network. The clustering coefficient for the entire network was 0.17. The highest clustering coefficient was 0.5, and there were 6 nodes with a clustering coefficient $\geqslant 0.2$.

IV. Discussion

A. *Comparative Analysis of the Global Microbial Meta Communty of WWTPs*

The average relative abundance values with in the continents were showing similar pattern with *Saprospiraceae*, *Rhodocyclaceae*, *Comamonadaceae* and *Chitinophagaceae* covering more than 34% of the total abundance of bacterial sequences (Figure 1). Thes pattern have also been reported by other authors who studied activated sludge system [12], [13]. From the Principal Component Analysis with 95% confidence level, we could not see clear distinguish between the microbial communities from different continents. How ever with the one-way ANOSIM results we identified South American microbial meta community is different from Asia and Europe which can be a resent due to the waste generation patters, climatic conditions and specific seed cultures used during the startup of the WWTPs used to sequence samples.

The identification of core constituents within the microbial community assumes significance in comprehending the in-situ processes facilitated by bacterial cells in WWTPs. Distinct bacterial taxa possess unique metabolic characteristics that intricately interact with nutrient removal procedures. Empirical models lack the capacity to forecast alterations transpiring within the intricate course of nutrient removal. Through the examination of core families within the community, environmental engineers can gain insights into the intricate material conversion processes. Consequently, this knowledge can aid in effectively maintaining the operational parameters of the WWTPs at desired levels, ensuring the anticipated efficiency in nutrient removal.

The advent of next-generation sequencing and rapid molecular identification techniques has provided WWTP designers with a comprehensive comprehension of the microbial community constituents [14]. This advancement surpasses the reductionist methodology employed in mathematical models. With the enhancement of computational capabilities, it has become feasible to discern various behaviors exhibited by the members of the WWTP community. Consequently, more precise estimations can be attained for any given type of WWT system. In this circumstance the identification of the core microbial members in the community will be crucial. With the increasing numbers of the cells the metabolic functions will have significant influence on the whole system.

B. *Network Analysis Revealed the Ecological Association Between the Families*

Pearson's correlations indicate the co-occurrence relationship between two identified nodes (bacterial families). The strength of co-occurrence is higher when positive correlations are observed, while it is weaker in the case of negative correlations between the ASVs [15].

Notably, a robust positive correlation was observed between the microbial families *Microscillaceae* and *AKYH767*, suggesting a potential mutualistic or synergistic interaction between these taxonomic groups. It is important to note that both families are commonly found in activated sludge derived from WWTPs. However, the precise ecological nature of this relationship cannot be definitively explained due to the absence of isolates and controlled ecological experiments [16].

The ASV identification method offers improved taxonomic resolution compared to the conventional Operational Taxonomic Units (OTU) approach [17]. This could explain the observed outcome of obtaining 39,251 ASVs through the bioinformatic analysis. Another contributing factor is the inclusion of multiple samples from different continents. Despite the presence of closely related microbial community members, employing a higher taxonomic resolution enables the detection of subtle differences between individual members from two samples at the species level. In this analysis, all ASVs within a specific family level had to be clustered together due to their low prevalence within the selected sample range.

Similarly, a negative correlation (R=-0.30) was observed between the microbial families *Sphingomonadaceae* and *Rhodocyclaceae*, indicating a potential ecological rivalry between these groups. Both of these families are known to encompass denitrifying polyphosphate-accumulating organisms (DPAOs) and denitrifying glycogen-accumulating organisms (DGAOs) [18]. In aerobic or anoxic conditions, DPAOs utilize nitrogenous compounds as the electron acceptor to assimilate phosphates from the substrate [19]. Likewise, DGAOs also employ denitrification as the electron acceptor. Given their shared functionalities that are closely associated with electron exchange and competition for substrate phosphate, *Sphingomonadaceae* and *Rhodocyclaceae* can be considered as competitors. Nevertheless, further confirmation of this putative interaction necessitates controlled experiments.

The findings of this study indicate that three families, namely *Microscillaceae*, *Sphingobacteriales (env.OPS 17)*, and *Chitinophagaceae*, have demonstrated notably high betweenness centrality scores (>0.15). These high scores suggest that these taxa may possess significant importance in preserving the structure and functionality of ecological communities. By identifying and separating the modules responsible for maintaining connectivity within the network, the utilization of betweenness centrality has proven valuable in identifying keystone species within the system [20].

Notably, the aforementioned bacterial families exhibit the third highest degree (6) among all the nodes in the network. This observation signifies their substantial connectivity with other bacterial families within the system [16]. Conducting a comprehensive investigation into the characteristics and behaviors of these bacterial families is of paramount importance, as their contributions are likely to be pivotal for achieving the desired functionality within WWTPs.

V. Conclusion and Future Work

This study provides valuable insights into the structures of microbial communities in activated sludge wastewater treatment plants (WTTPs) worldwide, specifically focusing on the family level. A methodology has been developed to identify biological interactions using a DNA fingerprinting approach, which serves as a proxy for detecting relative abundance. The findings of this study lay the groundwork for further analysis of functional gene expression and metabolic pathways. Subsequent investigations can be conducted to explore the relationships between metabolic pathways and nutrient removal processes, such as ANMAMOX [21], denitrification [22], EBPR [23], COMAMMOX [24] , among others.

The conclusions drawn from this meta-analysis warrant meticulous curation through a comprehensive examination of cellular metabolism. It is imperative to underscore that substantiating the hypotheses formulated in this study demands rigorous controlled experimental studies. Future investigations will involve laboratory-scale examinations wherein the metabolic conversion of the substrate will be conducted with a thorough functional genomic analysis. Notably, there is a pressing need to explore and curate the well-established rationale behind the robust association among microbial community members and the pathways intrinsic to the treatment process. This methodological approach presents a promising avenue for optimizing operations within Wastewater Treatment Plants (WWTPs) and elevating overall efficiency.

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2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

A Review in Micropropagation of Ornamental Aquatic Plants

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***Abstract*—Ornamental aquatic plant production is currently gaining much commercial attention, not just for its aesthetic value, but also for its other benefits. These benefits include preserving water quality in aquariums, improving water clarity and quality, reducing rates of shoreline erosion and sediment resuspension, and aiding in halting the spread of invasive alien plant species. These plants also provide important habitats for fish and wildlife in their natural environments. However, conventional plant propagation methods such as seed, stem fragments, root crowns, and rhizomes have their issues. These issues may hinder the effectiveness of commercial ornamental aquatic plant production. Micropropagation techniques can overcome these issues, and researchers have been investigating preferable protocols for these plants for the past few decades. Nowadays, new technologies are being evaluated to improve these protocols. This review aims to identify effective protocols suggested for some popular aquatic plants.**

Keywords—Ornamental aquatic plants, explant preparation, shoot and root induction, acclimatization

I. INTRODUCTION

Clonal propagation is widely used in crop production to preserve the desirable characteristics of specific genotypes or varieties in the progeny. Due to the process's cutting back, *in vitro* clonal plant propagation is also known as micropropagation [1]. By utilizing plant tissue culture techniques, micropropagation is a means of quickly growing stock plant material to generate a large number of offspring plants [2]. Plant tissue culture is a method for regenerating and propagating complete plants by cultivating isolated plant cells, tissues, and organs *in vitro* under axenic conditions. All plant cultures, including callus, cell, protoplast, anther, meristem, embryo, and organ cultures, are collectively referred to as "tissue cultures" in common parlance [3]. Plants are totipotent, meaning they can regenerate entire plants from individual cells or groups of cells within a tissue or organ, expressing the entire plant genome, in contrast to most animal cells [4]. That is the major reason plants can be regenerated under *in vitro* conditions. The success of plant regeneration via micropropagation depends on several factors such as explant, culture media, sterilizing agents and their application rates, and types of plant growth regulators used [2]. Currently, the most practical and economically efficient plant biotechnology is micropropagation, which quickly produces many clonal plants of many different plant species [4].

Compared to the traditional vegetative and reproductive methods available for plant propagation, micropropagation techniques possess more beneficial characteristics. Since cultures are started with extremely small pieces, maintaining or significantly increasing the number of plants only requires a small quantity of room. The disease incidences can be minimized because aseptic environmental conditions are provided throughout the period. Also, it is feasible to modify the variables that affect vegetative regeneration more flexibly, including temperature, light, and the concentrations of growth regulators and nutrients. As a result, a far higher propagation rate than with macro propagation is possible, resulting in the production of many more plants in a given amount of time. Another crucial factor is the potential to quickly and extensively introduce new technologies or newly bred plants and selections to the market. Other than that, less labor requirement, less energy and space requirement, output is more resilient to seasonal variations and can be carried out year-round, and clones of certain plant species that are otherwise slow, hard, or impossible to replicate vegetatively may be created [4], [5]. Currently, several plant species and varieties are being propagated through these techniques to attain the above-mentioned benefits. Among them, flowers and ornamental species (Orchids, Anthuriums), fruit crops (Banana,

Pineapple), plantation crops (Sugarcane), and vegetable crops play a major role [4].

The adaptations of aquatic plants allow them to survive in freshwater or saltwater settings. They can be divided into three groups: floating, bunch, and rooted plants. They are also known as hydrophytes or macrophytes. In the ornamental fishing sector, aquatic plants are important because they provide a pleasing appearance to the observation units and a variety of benefits for the occupants [6]. In addition to its aesthetic value, ornamental aquatic plants are used to preserve water quality in aquariums. These are chosen based on plant color, size, and shape [7]. In their natural habitats, aquatic plants can enhance water clarity and quality, lower rates of shoreline erosion and sediment resuspension, and aid in halting the spread of invasive alien plant species in addition to providing important habitat for fish and wildlife [8].

There are primarily two kinds of aquatic plant propagation techniques identified as asexual and sexual propagation methods [6]. Among them, seeds belong to sexual propagation and under the asexual propagation, propagules such as stem pieces, root crowns, or winter buds or tubers, which are dormant perennating organs can be identified [6], [8]. Several aquatic plant species are propagated through seeds or by division of rhizomes which is not a productive method and also it takes a longer time [7]. These facts lead to huge issues in commercial plant production. Due to their weakness, these propagules need almost perfect circumstances in order to be successfully established in artificial reservoirs. The majority of artificial reservoirs are doomed to failure in their tough surroundings. Another thing is that the natural production of some of the propagules can be seasonal [8]. Meantime some species are harvested from their natural habitats which leads to a huge issue in the sustainable growth of those plants [7].

Micropropagation techniques can be effectively used to overcome the issues in commercial aquatic plant production and propagation. Many studies have been conducted to determine the best conditions for each step of the micropropagation cycle, including explant sterilization, shoot and root induction, and acclimatization. The conditions required for each step may vary depending on the plant species and explant type used. In this review, we will identify micropropagation techniques introduced by different researchers for some aquatic plants like *Hemianthus callitrichoides*, *Rotala rotundifolia*, *Cryptocoryne* spp., *Anubias barteri* var. Nana, and *Limnophila aromatica*.

A. Hemianthus callitrichoides

Hemianthus callitrichoides 'Cuba' is one of the smallest aquarium plants in the world and belongs to the family Scrophulariaceae. When growing conditions are ideal, develops dense, carpet-like growth that spreads horizontally over the ground. In the tank, this growth pattern gives a lush and visually pleasing carpet impression.

- Explant Sterilization – Reference [9] tested for a better protocol to sterilize the explants of *H. callitrichoides*. As the sterilization of *H. callitrichoides*, the explants were washed, sterilized in double-distilled water, and divided into shoot clumps then surface-sterilized with 25% commercial bleach, NaOCl (Sodium hypochlorite), and 0.1% $HgCl_2$ (Mercury (II) chloride) for 5 minutes or 10% H_2O_2 (Hydrogen peroxide) for 45 minutes, followed by Mancozeb solution, and rinsed with distilled water and blotted on sterilized tissue paper. The shoot-clump explants were unable to be sterile on their surfaces with NaOCl and $HgCl_2$. They have concluded that for surface sterilization, H_2O_2 was more effective compared to the other treatments [9].

- Shoot Initiation- Similarly, according to [9], MS (Murashige and Skoog) media containing BAP (6-Benzylaminopurine) were the most suited and successful for the multiplication of shoots and their growth in a comparison of the tested other plant growth regulators [9]. For a wide range of *in vitro* applications, including callus induction, shoot regeneration, formation of roots, and somatic embryogenesis, MS media are frequently used. Another study showed that the full-strength MS medium and 1/2-strength POME (Palm Oil Mill Effluent) can give the highest growth index in *H. callitrichoides*. Then it has been demonstrated that 1/2 strength POME medium with liquid full-strength MS medium as a supplement is superior to full-strength MS medium and promotes the maximum growth of *H. callitrichoides* [10]. Sucrose serves as a fuel source for photomixotrophic metabolism during plant tissue culture, providing optimal growth. The shoots that were regenerated at greater sucrose concentrations were necrotic, limiting proliferation, and had a detrimental influence on chlorophyll synthesis [9]. The medium containing 4.5% sucrose showed the greatest weight gain, and the growing shoots were also more branched and vigorous [9].

- Root Initiation- For the root initiation, reference [9] used multiple regenerated shoots. For the *in vitro* rooting, an MS basal medium without PGR (Plant Growth Regulators) was used. On shoots that were grown on MS media lacking PGRs, rooting was encouraged [9]. In the media used to grow plants, agar is utilized to solidify and facilitate the healthy development of roots and the growth of culture. To grow larger clumps of *H. callitrichoides* with roots, the medium's solidification with 1 g/L agar was optimized [11].

- Acclimatization- For acclimation, the plantlets can be moved to aquariums with tap water and a foreground surface made of sand and gravel. Low light intensity during acclimation has an impact on plant development, however, *H. callitrichoides* is photophilic and cannot grow in low light levels [9].

B. Rotala rotundifolia

The perennial water plant *Rotala rotundifolia* has flexible stems that frequently branch to create low, creeping clusters. There are submerged and emergent variants of this species, and they differ in several ways as the submerged form features thin, lanceolate, sword-shaped leaves that are deeper green or

reddish, whereas the emergent form has fleshy, bright-green, rounded leaves [12].

• Explant Sterilization – To rid healthy plants of seaweed infestation, warm water can be used for washing. For *R. rotundifolia*, uninodal segments (0.5 cm) can be utilized. First, the pieces of rhizomes should be dipped in an ethanol solution (50% v/v) for 5-10 seconds, followed by washing in a NaOCl solution (1.5% w/v) for 20 minutes. They should be then rinsed in sterile distilled water and again dipped in the NaOCl solution (1.5% w/v) for 20 minutes. Finally, the *R. rotundifolia* uninodal segments can be cleaned using a 1.0% (w/v) concentration of NaOCl solution [13].

- Shoot Initiation- Reference [13] tested for a preferable shoot initiation medium for *R.rotundifila.* All leaves that exhibited no signs of bacterial or fungal contamination were grown on MS medium with 0.25, 0.50, 1.0, 1.50, and 2.0 mg/L BA (6-benzyladenine) fed with 3% sucrose and 0.65% agar solidified in magenta GA3 (Gibberellic Acid) containers for regeneration. A maximum number of shoots per explant was obtained from MS medium containing 2.00 mg/L BA and 0.20 mg/L GA3 [13].

- Acclimatization- Two different basal substrate layers should be placed at the bottom of the tank with 150 mm thickness. The first one should be composed of peat, fine clay, and sand (1:1:10 / v: v: v), and the second one should be like natural soil. All substrates should be autoclaved, and substrates should be maintained completely submerged. The rooted clumps (plantlets) can be directly acclimated in a PVC and glass tank (110 x 40 x 55 cm) that contains 160 L of deionized water and can be pre-conditioned at a 16-hour photoperiod and 25 W of artificial light. The aquarium's temperature should be kept between 20 and 25 °C [7].

C. Cryptocoryne spp.

With roughly 50–60 species of aquatic monocot plants, the genus *Cryptocoryne*, also known as the "water trumpet," is significant within the Araceae family of plants. Popular aquarium plants, the majority of *Cryptocoryne* species are native to Southeast Asia and flourish in both submerged and emerging states [14].

a. Cryptocoryne lucens

- Explant Sterilization – A proper explant sterilization protocol was found in reference [15]. After defoliating the aerial plants of *C. lucens*, 1.0 cm nodal explants were separated and cleaned in running tap water for one hour. The explants were then surface-sterilized by immersing them first in 50% (v/v) ethanol for one minute, then in 105% (w/v) NaOCl for 12 repetitions, followed by three rinses of five repetitions each in sterile distilled water [15].

- Shoot Initiation- Similarly shoot proliferation from different explant types (single and clustered triple-node shoot explants) was observed on Linsmaier and Skoog salts and vitamins medium (LS) with 20 µM BA and 0.5µM NAA (1-Naphthaleneacetic acid) solidified with 0.8% (w/v) agar. The total number of shoots produced per explant was significantly greater from triple-node explants. All shoots on BA-supplemented media rooted and developed dark green leaves with red margins and petioles [15].

- Rooting and Acclimatization- Four cells with dimensions of 6.1 × 3.8 × 6.0cm were used to transfer the rooting medium of triple-node micro-cuttings. To maintain high humidity, a clear vinyl propagation dome was used to cover the tray. The tray was soaked weekly with 20:13.9:3.7 (N: P: K) liquid fertilizer, containing 150 mg N/L. After 3 weeks, the propagation domes were progressively removed over 5 days to reduce humidity and help the plantlets acclimatize. The trays were then moved to a lightly shaded greenhouse with heating and cooling set temperatures of 18 and 29ºC, respectively. After 18 weeks, the plants had survived well and produced large leaves. Finally, the plants were acclimatized, and after 30 weeks, they started flowering [15].

b. Cryptocoryne beckettii

- Explant Sterilization – According to reference [14], *C. becketti* mother plants' shoot tips can be separated, and they are washed thoroughly under running tap water. After which it should be cleaned with sterile distilled water and soaked for 1 minute in 70% ethanol. They can be surface-sterilized for 15 minutes using a 200 mg/L (w/v) $HgCl_2$ solution, and then they should be thoroughly rinsed three times with sterile distilled water. Finally, they should be surface sterilized again for another 15 minutes using 15% Clorox solution (containing 5.3% NaOCl), 2–3 drops of Tween 20, and washed three times with sterile distilled water [14]. However, reference [7] showed that the rhizome of this plant also can be used as an explant. It has to be washed in warm water and separated into 1cm long pieces. The portions of rhizomes should be washed in ethanol solution (50% v/v) for 5 - 10 seconds and then dipped in NaOCl solution (1.5% w/v) for 20 minutes. Finally, the explants should be rinsed in sterile distilled water [7]. Similarly, reference [16] also used the rhizome of this plant as the explant. There *C. beckettii* rhizomes were washed well with soap and water and rinsed under running tap water for six hours. Then, overnight they were immersed in a fungicide [3% (v/v) 'thiophanate methyl' 70%'] solution. The rhizomes were washed again for one hour under running tap water, dipped in 70% (v/v) ethanol for 1 minute and 20% (v/v) NaOCl for 15 minutes. Finally, the explants were thoroughly washed five times with sterile distilled water [16].

- Shoot Initiation – According to the study conducted by reference [14], a higher shoot proliferation was formed after four weeks from MS medium supplemented with 0.5 mg/L BA + 30g/L sucrose and without agar [14]. For the shoot initiation of *C. becketti*, the explant was vertically positioned in LS medium, supplemented with NAA (0.5 mg /L) and BAP (2.0 mg/ L) in the study conducted by reference [7]. The cultures were transferred to a growing room and maintained at 22 ± 1°C and 16 hours of light photoperiod, under cool white fluorescent light. Then after six weeks, shoots were transferred to the higher multiplication medium of LS medium + 4 mg/ L of BAP [7]. In

the study conducted in reference [16], rhizomes were cut into 1cm length fragments and placed horizontally on full-strength MS medium with 3% sucrose. Finally, they were grown under white fluorescent light with a 16-hour photoperiod for shoot regeneration. After six weeks, they were grown on shoot multiplication media using MS medium + 5.0mg/L BAP + 0.1mg/L IAA (Indole-3-acetic acid) and obtained the highest mean number of shoots per shoot explant [16].

- Root Initiation- After four weeks in the study conducted in reference [14], root proliferation was observed in MS medium supplemented with 0.5 mg/L BA and 30 g/L sucrose, without agar [14]. Reference [7] found that transferring *C. becketti* plantlets to a low concentration of BAP (1mg /L) on LS medium with a higher number and length of roots resulted in better growth [7]. After eight weeks of culture on root initiation medium containing half-strength liquid MS supplemented with 0.1 mg/L NAA, plantlets in the study conducted in reference [16] achieved the highest mean root number, root length, and shoot height [16].

- Acclimatization- Eight-week-old rooted micropropagated *C. becketti* plantlets were thoroughly washed with running tap water before being acclimatized into plastic pots (20 x 20cm) in reference [14]. The acclimatization medium, which contained a mixture of compost and sand in a 1:1 ratio, was overlaid with tap water and placed under greenhouse conditions. The plantlets were exposed to a relative humidity of 80-90% and a temperature of 28 ± 2 ºC during the daytime and 24 ± 2ºC during the nighttime [14]. Reference [7] discovered that the rooted plantlets can be acclimated in an aquarium tank that has a size of 110 x 40 x 55 cm and contains 160 L of deionized filtered water. The tank should be maintained at a temperature between 20 and 25°C and have a pre-conditioned 16-hour photoperiod with 25W artificial light. At the bottom of the tank, a 150-mm layer of autoclaved basal substrates composed of peat, fine clay, and sand (in a ratio of 1:1:10 by volume) should be placed. After 15 days, all plantlets were found to have survived at 100% [7]. After eight weeks, the well-rooted plants in the reference [16] study were acclimated in clay pots with a mixture of sterile clay and sand in a 2:1 ratio. The plants were provided with sterile distilled water to a height of 1 cm. As a result, the plants survived very well [16].

D. Anubias barteri var. Nana

Anubias barteri var. Nana is a valuable aquatic plant that grows completely submerged in water and belongs to the Araceae family. It is widely used to enhance the well-being of ornamental fish and to create more lifelike aquarium decorations. Consequently, the demand for this plant is increasing globally daily [19].

- Explant Sterilization – In the study conducted by reference [19], the explant they used was stem nodes and for the surface sterilization, explants were rinsed in double distilled water after an hour of being cleaned under running tap water. After that, surfaces were disinfected for 10 minutes with a 25% commercial bleach solution and 15 minutes with a 75 mg /L antifungal solution (Mancozeb). After one more rinsing for 3 × 7 minutes with sterile double-distilled water, the explants were blotted on sterile tissue paper. Another study has shown that shoot tips can be used as the explant. There the plantlets were surface sterilized by using a 0.5% (w/v) $HgCl_2$ solution with two drops of Tween-20 emulsifier per 100 ml solution for a period of three minutes. To remove any residual disinfectant, the treated plantlets were rinsed three times with sterile distilled water. Afterward, the explants were subjected to another round of surface sterilization, this time with a 10% (v/v) dilution of commercial Clorox, which contains 5.25% NaOCl and 2 drops of Tween 20 per 100 mL solution. The explants were left in this solution for 15 minutes, followed by a 5% (v/v) Clorox solution for an additional 5 minutes. Finally, the explants were cleaned three times with sterile distilled water to complete the surface cleaning process [18].

- Shoot Initiation–Reference [17] found that the highest axillary shoot induction was observed on both half and full-strength MS media containing 0.25 and 0.50 mg /L GA3 respectively while the media were supplemented with a constant concentration of 0.10 mg/L BAP and 0.10 mg /L NAA. According to reference [18], in MS media supplemented with 3 mg/L BA, the greatest number of shoots per explant was achieved. The findings indicate that BA applied alone was critical for *A. barteri* var. Nana's activation of axillary bud development [18].

- Root Initiation–In the study conducted by reference [18] they revealed that on MS media free of plant growth regulators or kinetin alone, rooting in all regenerated shoots was encouraged [18].

- Acclimatization–The tap water-filled aquarium effectively acclimated the in vitro regenerated *A. barteri* plantlets without exhibiting any signs of mortality. Low photosynthetic photon flux (PPF) during acclimation, yet, had an impact on the growth of regenerated plants. Recall that *A. barteri* is a light-loving plant that might not thrive in a dark environment [17].

E. Limnophila aromatica

Also known as Rice paddy herb it is a tropical and stout aromatic herb 30-50 cm in height and belongs to the family Plantaginaceae [19]. This plant is native to Southeast Asia and typically grows in flooded rice fields and is commonly used as an aquarium plant [20].

- Explant Sterilization–To prepare *L. aromatica* plants for surface sterilization, they should be placed under running tap water for 15 minutes. First and second-node explants, which include the meristematic region, should then be treated with 20% and 30% NaOCl for 10 minutes, respectively [21]. If not, H_2O_2 can be used at a rate of 16% (v/v) for 10 minutes, followed by rinsing the plant tips with sterilized distilled water three times in five minutes. For propagation, sterilized twigs with 1-2 cm pieces and one to two nodes should be used and cultured on a suitable medium for 15 days. Reference [22] used shoot tips and young leaves as explants in their study [22].

- Shoot Initiation- In the study of reference [22], surface-sterilized shoot tip explants were inoculated on MS medium supplying 0.25-2.0 mg/L BA+ 0 and 0.25 mg/L NAA. Shoot regeneration frequency on the test was 100% of any culture [22]. Reference [21] demonstrated that callus could be generated from nodal explants by adding TDZ (Thidiazuron) and 2,4-D (2,4-Dichlorophenoxyacetic Acid) to the MS medium at a concentration of 0.25 mg/L each. The calli were then cultured in MS medium supplemented with 0.50 mg/L of kinetin. The MS nutritional medium was prepared using 3% sucrose [21].

- Root Initiation–According to reference [22], after culturing for a period of 8 weeks, when the isolated shoots were placed on a rooting medium containing 0.25-1.0 mg/L NAA, regardless of the concentration, rooting began within 8-10 days. After 4 weeks of culture, 100% rooting was observed. For both shoot induction and root initiation, the culture media must contain 30g/L (W/V) sucrose and 0.65% (W/V) agar at a pH of 5.8 [22].

- Acclimatization–In the study conducted by reference [23], it was found that the addition of water during the culture process had a positive impact on the growth and acclimatization of multiplied *Limnophila* plants. These plants are able to grow both in the presence and absence of water. After the addition of water, the morphology of the plant's leaves changed from aerial to submerged, with thinner and more linear leaves [23].

II. Conclusion

Micropropagation is a widely used asexual plant propagation technique in agriculture, particularly in the horticultural crop sector. The ornamental aquatic plant industry is experiencing a continuous increase in demand worldwide, being highly important for aquariums and water resource rehabilitation projects. However, traditional propagules pose several issues, making the use of advanced technologies like micropropagation a potential solution for commercial plant production. Research has focused on finding preferred protocols to culture ornamental aquatic plants, using different explants depending on the species. Choosing the best protocol is crucial for efficient plant production. As well as maintaining a healthy mother plant stock, breeding new varieties, and identifying potential hidden benefits through the fundamentals of plant tissue culture is important to the growth of this subject area.

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2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

Aqueous Extraction and Dyeing Behavior of Areca Nut (*Areca catechu*) Natural Dye for Cotton Fabric

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***Abstract*—The objective of this study is to extract and characterize the natural dye from the powder waste of Areca nut (*Areca catechu*), which is a plant that is widely found in tropical Asia, East Africa, and the Central Pacific regions. The study also aims to develop a recipe for dyeing cotton fabric using this natural dye. The aqueous extraction method was used to extract the *Areca catechu* dye. Two different metal mordants (Aluminium potassium sulfate (Alum) and Ferrous sulfate) and two mordanting techniques (pre-mordanting and post-mordanting) were used at 3% and 5% concentrations to set the extracted dye on the cotton fabrics. The extracted dye exhibited a pH value of 4.0, presented a distinct reddish-brown hue, and showed absorption spectra in the UV-A and visible light regions. The presence of functional groups was determined by FT-IR analysis of the extract. Dyed cotton samples displayed good colorfastness properties, particularly in washing and light fastness. Color intensity values were measured in terms of color strength (K/S) and Color space values (CIE Lab values). K/S values indicated that dyeing with ferrous sulfate had the highest color strength values. Using different mordants causes not only the difference in color strength but also the color properties. Thus, the dye extracted from *Areca catechu* can be used with a suitable mordant for the coloration of cotton fabrics. The future study of *Areca catechu* natural dye should focus on the economic viability of producing the dyes commercially.**

Keywords—Areca nut, characterization, extraction, natural dye, textile

I. INTRODUCTION

Due to the environmental issues associated with synthetic dyes, there is an increased interest in environmentally friendly coloring options, including safer synthetic and natural dyes. Most importantly, natural dyes offer the advantages of being derived from renewable sources and biodegradability, resulting in minimal environmental impact [1]. Natural dyes are derived from various sources, including plants, animals, and minerals [2]. They are increasingly favored by consumers, having a global demand exceeding 10,000 tonnes annually. Natural dyes are highly valued for their ability to reflect cultural heritage and unique aesthetic qualities that synthetic dyes cannot replicate [3].

Among all natural dyes, those derived from plant sources hold significant potential due to their widespread availability. Plants such as madder, henna, weld, and indigo have been extensively utilized [4]. Areca nut, or betel nut (*Areca catechu*), is a slender palm tree belonging to the Arecaceae family, and it is widely distributed in tropical Asia, East Africa, and the central Pacific regions [5]. *Areca catechu* nuts are rich in tannins, which can be utilized as a natural dye for the textile industry [6].

A substantial amount of waste is generated in *Areca catechu* processing factories such as "Supari," "pan masala," or "Sarawita. The waste primarily includes dust, unripe, and molded nuts, which are typically disposed of by burning. Effectively utilizing this agricultural waste would address disposal issues and provide an additional source of income for the farmers and processing industries. The presence of tannin in *Areca catechu* waste offers opportunities for dye extraction, potentially mitigating waste accumulation while providing economic avenues for agricultural communities.

This research aims to extract and characterize the natural dye from the powder waste of *Areca catechu* nuts using aqueous extraction and to explore the feasibility of integrating *Areca catechu* waste-derived natural dye into industrial fabric dyeing processes.

II. METHODOLOGY

A. Materials

In this experimental study, Areca nut (*Areca catechu*) powder, a waste product of *Areca catechu* processing factories, was collected from a factory in Matale, Sri Lanka. A 100% plain-woven bleached cotton fabric (weight of 80 gm^{-2} with ends per inch (EPI) and picks per inch (PPI) of 58 and 72) was purchased from "Janasalu," Department of Industrial Development, Kurunegala, Sri Lanka. The laboratory-grade chemicals of Ferrous sulfate ($FeSO_4$, Sigma Aldrich, UK) and Aluminum potassium sulfate ($KAl(SO_4)_2.12H_2O$, Alum, Fluka, Germany) were purchased from chemical suppliers in Colombo, Sri Lanka. Distilled water (laboratory water distiller-Bionics Scientific Technologies, India) was used in dye extraction and chemical preparations. All the chemicals were used without any additional purification.

Fig. 1: *Areca catechu* powder waste

Fig. 2: Aqueous dye extract

B. Methods

1) Dye Extraction

Areca catechu powder was grinded and then sieved using a 250 µm sieve to obtain a uniform particle size (Fig. 1). The Sample was oven-dried at 105 ˚C for 5 hours for moisture content determination.

A mixture comprising 10 g of *Areca catechu* powder and 4 g of Sodium Chloride (NaCl) was mixed with 200 ml of distilled water, following a ratio of 1:20. This mixture was left to stand overnight. Subsequently, it was heated to 70 °C and stirred for 3 hours continuously, as shown in Fig. 2. The mixture was then allowed to cool to room temperature and filtered using a mesh fabric. The resulting aqueous dye extract was then used for further dyeing studies with cotton fabric.

2) Mordanting

Dyeing was carried out with different mordants and without any mordants. Two specific mordants, namely Ferrous sulfate ($FeSO_4$) and Aluminum potassium sulfate ($KAl(SO_4)_2$/Alum), were used in this study. Two Mordanting methods, Pre-mordanting and Post-mordanting, were performed at a temperature of 80 °C for 2 hours. The amounts of mordant added were 3% and 5% (the amount of mordant used from the fabric weight), and distilled water was used for the mordanting process.

For the pre-mordanting technique, a solution was prepared by dissolving the mordant in distilled water, using two mordant concentrations. The material-to-liquor ratio (MLR) employed was set at 1:30. Subsequently, the fabric samples were carefully squeezed to remove excess liquid and allowed to air dry for a few minutes.

For the post-mordanting approach, fabric samples were initially dyed and then mordanted using the two above-mentioned mordants at two different concentrations. The MLR remained consistent at 1:30 throughout this stage. The fabric samples were then squeezed to remove excess liquid and allowed to air dry.

3) Dyeing

In the dyeing process, the fabric was dyed at its initial pH value. 5 g of 100% mercerized cotton fabric was dyed using 200 ml of the dye solution at a temperature of 70°C, maintained for 2 hours. The MLR utilized for this step was 1:40.

4) Dye Characterization

a) pH Value Analysis

The pH level of the dye solution influences the dyeing behavior during dyeing, impacting solubility and color outcome. It was measured using a digital pH meter (S-610H pH meter, PEAK Instruments, USA). Three pH readings of the dye solution were taken using the pH meter, and the first reading was removed. The average pH value was calculated using the second and third readings.

b) Fourier-Transformed Infrared Spectroscopy (FTIR) Analysis

The determination of specific functional groups of *Areca catechu* dye was measured by Fourier transform infrared (FTIR) spectroscopy (Vertex 80, Bruker Corporation, USA). The samples were placed in FTIR-ATR mode at 600-4000 cm^1.

c) Ultraviolet-Visible (UV-Vis) Spectral Analysis

The absorbency of the wavelength of the aqueous dye extract was determined using Ultraviolet-visible (UV-Vis) spectroscopy (UV-3600i Plus, Shimadzu Corporation, Japan). The extracted dye was then diluted by dissolving 1 ml in 50 ml of Deionized water to measure its absorption spectrum under a range of wavelengths (200 nm–800 nm).

5) Evaluation of Dyed Fabric Color Characteristics

Color evaluation was done through various fabric color characterization methods on the dyed fabric samples.

a) Colorfastness Assessment

The dyed fabric samples were subjected to rigorous colorfastness assessments, encompassing various conditions such as exposure to light, rubbing, and perspiration. The colorfastness of *Areca catechu* dyed fabric was evaluated in accordance with the respective international standards, including fastness to washing (ISO-105-C06-2010), fastness to rubbing (ISO-105-X12-2016), and fastness to light (ISO-105-B02-2014). The changes in the shade and the staining of the adjacent multi-fiber fabric were assessed using grey scales [7].

b) Evaluation of Color Strength and Color Space of Dyed Fabric Samples

The color strength of the dyed fabric samples, indicated by their K/S values, measures the extent of light absorption at the maximum absorption wavelength. Higher K/S values signify more intense colors. The color strength (K/S) values of the dyed fabric samples were determined using the "Kubelka-Munk" equation [8].

$$K/S = (1–R)^2/ 2R \quad (1)$$

Where R is the reflectance of the dyed fabric, K is the absorption coefficient, and S is the scattering coefficient.

The reflectance of the dyed samples (R) was measured using the Data Color spectrophotometer (DC 800 Spectrophotometer, Datacolor Technologies Suzhou Corporation, China). The color strength values of the dyed fabric samples were determined using the ratio of absorption (K) and scattering (S) coefficients (K/S) in the Data Color

tools plus software (built-in software in the spectrophotometer).

These color strength values served as quantitative indicators to express the color characteristics of the dyed fabric samples. The color properties were further analyzed within the Commission International de l'Eclairage (CIE) color space. The CIE Lab color space values are expressed as three-color values: L* represents the perceptual lightness from black to white, and a* and b* represent the four colors: red, green, blue, and yellow. a* represents the green–red colors within a range of; b* represents the blue–yellow colors within a range of [9].

III. RESULTS

A. Dye Characterization

1) pH Value Analysis

Without mordanting agents, an aqueous solution of *Areca catechu* dye exhibited a pH of 4.0 and a distinct reddish-brown hue.

2) UV–Vis Spectroscopic Analysis

Fig. 3 presents the UV spectrum of *Areca catechu* aqueous extract dye in an aqueous solution. The spectrum exhibits absorptions in the 357 nm and 478 nm regions, indicating the presence of tannin compounds in the dye and yellow color in the *Areca catechu* aqueous extract, respectively [10], [11]. The dye molecules readily absorb radiations in the UV-A region (320-395 nm) and visible light range [12]. UV-A is the long wave UV wavelength that makes up approximately 95% of the UV radiation that reaches the Earth and it is the primary cause of photo aging, wrinkling, skin cancer, and eye damage because of it can penetrate the dermis layer of skin [12]. AS a result, this absorption in the UV-A region can provide excellent protection against harmful UV radiation.

3) Fourier-Transformed Infrared Spectroscopy (FTIR) Analysis

The FTIR spectra obtained for extracted *Areca catechu* (aqueous extract) are shown in Fig. 4. The presence of –OH groups was indicated by the peak at 3376 cm^{-1}. The –CH group stretching corresponding to the peak at 2921 cm^{-1} [13] and a C=O bond at 1615 cm^{-1} were observed [14]. The aromatic C=C bond is found at 1414 cm^{-1} wavenumber [13], while the stretching of the C–O group was observed in the spectrum near 1275–1200 cm^{-1} [14]. Furthermore, the peaks at 1070 cm^{-1} and 795 cm^{-1} indicate fluoroalkane (C-X) and C=C bonds, respectively [14], [15].

B. Color Evaluation

When the fabric is submerged in the dye solution, it quickly takes on a brownish color, and in the presence of a mordant, the color changes accordingly. The dyeing depth can be improved using different metal salt mordants in both methods. When ferrous sulfate is used as the mordant, the fabric turns to a darker shade. The presence of Alum as the mordant caused a brighter yellowish shade on the fabric. The color chart of the dye is shown in Table 1.

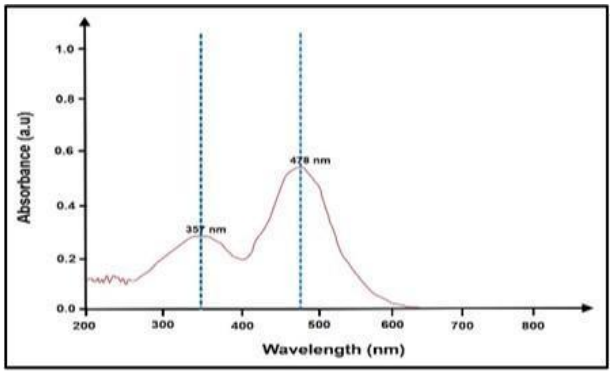

Fig. 3: UV-Vis spectral analysis of Areca catechu-aqueous extract

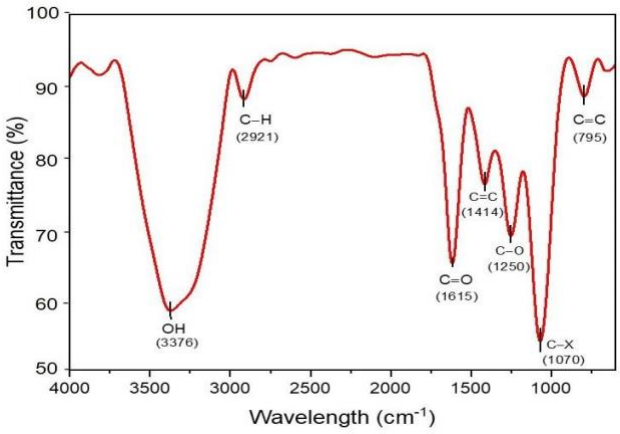

Fig. 4: Fourier transform infrared spectra of Areca catechu dye- Aqueous extract

TABLE 1: COLOR EVALUATION OF *ARECA CATECHU* DYE

Mordant type		Color shade	
Non			
		Mordanting method	
		Pre	Post
$FeSO_4$	3%		
	5%		
Alum	3%		
	5%		

C. Colorfastness Properties

The fastness properties of dyed fabric samples can be altered based on the type of mordants used, the method of mordanting, and the concentration of the mordant. To determine how much the dyed cotton sample can withstand washing, light, and rubbing, the color fastness test must be carried out.

Tab. 2 displays the colorfastness characteristics of cotton fabric dyed with *Areca catechu* dye. In comparison to the mordanted samples, the non-mordanted sample showed poor fastness to washing with a color change of 2-3. The rating for colorfastness to washing for both Alum and Ferrous sulfate appears to be above 4 for color change except for the Alum 3% pre-mordanted sample. According to the wash

fastness results shown in Table 2, both substrates showed outstanding color staining values of 4-5 and 5. The method of mordanting appears to have the same effect on the color fastness of washing cotton fabric dyed with *Areca catechu* dye for both the mordanting agents used. This indicates excellent fastness to washing.

Colorfastness to light for cotton dyed with this dye in the absence of any mordanting agent was improved upon the application of ferrous sulfate and alum as the mordanting agents for both the mordanting methods. There is a high light fastness for ferrous sulfate which had excellent color change values of 4-5 or above, and fabric samples mordanted with Alum displayed lower color change values compared to ferrous sulfate. Furthermore, the ratings of post-mordanted fabrics dyed by 3% and 5% of ferrous sulfate are higher than the pre-mordanted fabrics.

With the use of mordants, the rub fastness of the cotton samples has improved slightly. The rub fastness of the cotton samples was better for wet rubbing than for dry rubbing. With very few exceptions, the tested samples displayed a grey scale rating of 4 for wet rubbing. On the other hand, for dry rubbing the grey scale rating was 3-4.

D. The Color Characteristics of The Dyed Fabrics

Color characteristic values of the dyed cotton fabrics resulting from the dyeing process are shown in Fig. 6. It shows the dye uptake of the dyes in terms of K/S values at different concentrations and different mordanting methods. It has been observed that using ferrous sulfate as a mordant significantly improves the K/S values. Among the chemical mordants used, 5% ferrous sulfate has the highest color strength value (K/S = 6.44). An improvement in the K/S value of the dyed samples denotes a higher amount of dye adsorption, interaction, and bridging with the pre-mordanted substrate via different conjugated bonds.

There are variations in hue color as well as significant changes in K/S values, L* values, and brightness index values with the type of mordant used. Fig. 5 shows the CIE L* a* b* values of dyed cotton fabrics with *Areca catechu* aqueous extract. It can be seen that the fabric samples with lighter shades give a higher value of L*, while those with a darker shade have a lower L* value. The L* values were lower for the fabric samples dyed using ferrous sulfate, corresponding to deeper shades. The L* value was higher for non-mordanted dyed samples, corresponding to lighter shades. Similarly, using Alum, the L* values were also higher, leading to lighter shades. Positive values of a* and b* represent shades of red and yellow, respectively. Also, higher values of a* and b* indicates brightness, which denotes the red and yellow hues, respectively.

TABLE 2: FASTNESS PROPERTIES OF COTTON FABRIC DYED WITH *ARECA CATECHU* DYE

Mordant	**Mordant concentration**	**Mordanting method**	**Wash fastness**		**Lightfastness**	**Rubbing fastness**	
			Color Change	**Color Staining**	**Color Change**	**Dry staining**	**Wet staining**
Non	-	-	2-3	4	2-3	3	3
$FeSO_4$	3%	Pre	4	4-5	4	3-4	3-4
		Post	4	5	4-5	4	4
	5%	Pre	4	4-5	4	3-4	3-4
		Post	4	4-5	4-5	3-4	4
Alum	3%	Pre	4-5	5	3-4	3-4	4
		Post	4	5	3-4	3-4	4
	5%	Pre	4	4-5	3-4	3-4	4
		Post	4	4-5	3-4	3-4	4

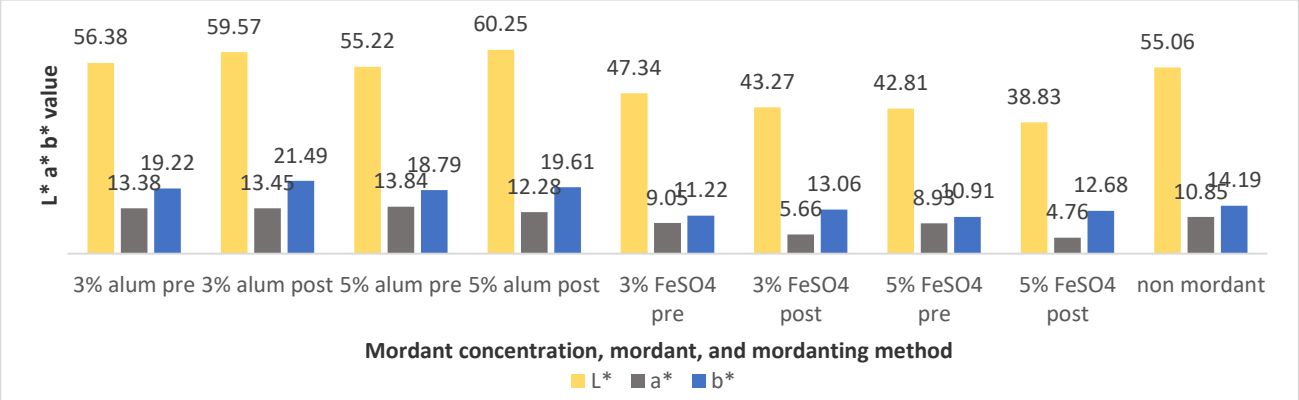

Fig. 5: L*a*b* value comparison of cotton fabric dyed with Areca catechu - Aqueous extract

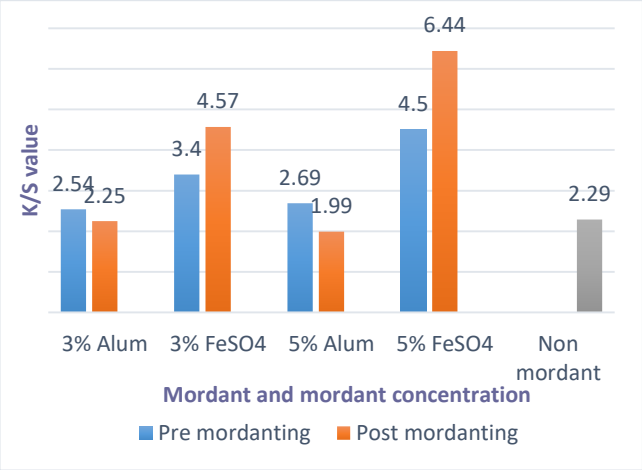

Fig. 6: K/S value comparison of cotton fabric dyed with Areca catechu - Aqueous extract

It can be seen that the b* value of all the dyed fabrics ranged from 10.91 to 21.49, which represents the yellow color. The a* value varied from 4.76 to 13.84, which shows the dyeing colors obtained from all the dyeing processes were mainly red. Using alum as the mordant has increased the quality of the red tone, while ferrous sulfate has caused a reduction in the quality of the red tone.

The mordanting process showed an impact on the quality of the yellow tone, which can be seen from the b* value of the mordanting methods: post-mordanting> pre-mordanting> non-mordanting. The b* values of the dyed cotton fabrics show that the dyeing colors obtained from all the dyeing processes were mainly yellow.

IV. Conclusion

This research is focused on the potential of *Areca catechu* as a natural dye for cotton fabric. *Areca catechu* dye, extracted through aqueous extraction, demonstrated its capability to impart unique color characteristics to cotton textiles. Without mordanting agents, the aqueous solution of *Areca catechu* dye extract exhibited a pH of 4.0, presenting a distinct reddish-brown hue. The dye has absorption spectra in the UV-A region and visible light region. The structural analysis of the functional groups in each extract was established using FTIR spectroscopy. The color evaluation results showed that the addition of mordants significantly influenced the color outcomes. Ferrous sulfate resulted in a darker shade, while Alum produced a brighter yellowish tone. Additionally, the mordanting process positively affected colorfastness properties, particularly in washing and light fastness. K/S values indicated that dyeing with ferrous sulfate yielded higher color strength values. L* values were found to be lower when ferrous sulfate was used, which correlates to deeper shades. Alum gives higher value of L*, which corresponds to lighter shades. The results revealed that cotton fabrics mordanted using 5% ferrous sulfate by post-mordanting gave the optimum color strength with good fastness properties. Further research can explore the optimization of dyeing parameters and investigate the potential for scale-up production of *Areca catechu*-based dyes for commercial applications.

Acknowledgment

All authors wish to extend their sincere gratitude to Mr. M.T.M.R. Jayaweera, Mr. M.A.P.C. Gunawardhana and Mr. R.R.P. Perera of the Department of Materials Science of University Moratuwa and Mr. C.P. Malalanayake, Mrs. D.M.D.S. Dissanayake and Mr. K.D.T.A. Kumara of the Department of Textile and Apparel Engineering of the University of Moratuwa.

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2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

Modelling Land Suitability for Optimal Rice Cultivation in Ebonyi State, Nigeria: A Comparative Study of Empirical Bayesian Kriging and Inverse Distance Weighted Geostatistical Models

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***Abstract*—This study addresses the diminishing yields and food insecurity caused by declining rice production, a critical staple in Nigeria. Focused on Ebonyi State, the research employs GIS-based land suitability analysis to pinpoint the most suitable locations for rice cultivation. Environmental variables such as geology, soil types (Nitisols, Acrisols), elevation (0-28 m), slope (0-48%), and hydrology are examined. Geostatistical methods, including Empirical Bayesian Kriging (EBK), Inverse Distance Weighted (IDW), and Radial Basis Function (RBF), are used to model spatial variations. Multiple linear regression establishes quantifiable relationships between these factors and rice suitability. Analysis of Variance (ANOVA) underscores the significant impact of local government (p=0.0217), community, and water source (p=0.0431) on suitability. Central Ebonyi exhibits the highest flow accumulation (160.53 ratio). EBK emerges as the most accurate model with a Root Mean Square Error (RMSE) of 12.61. Regression models emphasise the influence of administrative factors on suitability. The study's results not only shed light on environmental constraints and opportunities but also offer crucial insights for enhancing rice productivity. This information is pivotal for shaping agricultural practices, and policies, and ultimately improving food security. Policymakers, agricultural agencies, and farmers stand to benefit significantly from the study's key findings, guiding them in selecting optimal cultivation sites, implementing effective practices, and making informed decisions to foster efficient and sustainable rice farming in Ebonyi.**

Keywords*—Rice cultivation, agricultural sustainability, food security, GIS, land suitability analysis, geostatistics, environmental factors, multiple regression, ANOVA

I. INTRODUCTION

Rice is of considerable economic importance in many developing countries and has become an important crop in many developed countries where consumption has increased significantly. With the rapid growth of the world's population, it has become necessary to meet the growing demand for rice [1]. Rice farming plays a crucial role in Nigeria because it serves as a staple food and has a significant impact on the country's economy. Nigeria holds the distinction of being a major producer and consumer of rice within Africa [2]. However, despite its domestic production capacity, Nigeria also relies on substantial imports of rice [3].

The decreasing crop yields, particularly in the case of rice, in Nigeria can be attributed to various factors [4]. These include fluctuating climatic conditions, increasing pressure on land due to population growth and the subsequent reduction in farm sizes, instability and migrations resulting from ethnic conflicts and conflicts between farmers and herders, and the inability of peasant farmers to access fertilizers. Additionally, conservative attitudes toward modern agricultural techniques and market forces act as disincentives, along with challenges related to soil quality, terrain, and relief. According to Food and Agriculture Organization [2]. Nigeria's Ebonyi state is a significant rice-producing region. Onyeneke et al., 2021 noted that Ebonyi state's prevailing climatic conditions and excellent soils are ideal for growing rice. To increase rice productivity while ensuring land and environmental sustainability, countries must adopt an integrated approach that improves their ability to effectively plan and monitor the optimal utilisation and management of their land resources [5]. Geographic Information System (GIS) based analytic hierarchy process (AHP) multi-criteria analysis is one such integrated approach employed by [6, 7] a assess land suitability for rice cultivation in the great Mwea region, Kenya. To align rice farming with environmental sustainability while maximising economic outputs. This study aimed at utilising GIS-based multi-criteria decision model (MCDM) land suitability analysis in conjunction with the Food and Agricultural Organization (FAO) framework to identify suitable and

unsuitable land for rice cultivation in the designated area. Researchers in [5, 8, 9, 10, 11] have employed diverse methods and models to assess the variability of essential spatial properties and their impact on rice cultivation. These spatial properties frequently include elements such as soil composition, which includes important characteristics such as nutrient content, pH levels, and water retention capacity. Furthermore, researchers examine elevation data to better understand how an area's physical landscape, such as slopes or contours, affects water drainage and irrigation practices. Climate variables, land cover types, and proximity to bodies of water may also be considered. Those methods unveiled relationships between environmental factors and rice crop performance by analysing these spatial properties. This improves site selections, agricultural practices, crop yield, and overall farming efficiency.

[12, 13, 14, 15] Highlighted that land suitability analysis is a necessary step in making the best use of available land resources. Low agricultural yields have been exacerbated by a lack of understanding of the optimal combination of factors suitable for rice production. The studies used advanced tools and methodologies such as geospatial analysis, remote sensing, and geographic information systems (GIS) multi-criteria assessment using the analytical hierarchy approach to provide powerful tools for integrating multiple data layers and extracting meaningful insights and to address the challenges associated with managing and analysing large amounts of spatial data for rice land suitability assessment. Hence, the primary aim of this current research is to utilise an ensemble approach and conduct a comparison of geostatistical models and niche modelling techniques. The study seeks to account for spatial variability and autocorrelation to generate a comprehensive land suitability map specifically for rice cultivation in Ebonyi state, Nigeria.

II. Materials and Method

A. Study Area Description

Ebonyi State is one of Nigeria's 36 states, located in the country's southeastern region. The state is bounded to the north by Benue State, to the west by Ebonyi State, to the east by Cross River State, and to the south by Abia State. According to the most recent estimates, Ebonyi State has a population of approximately 3 million people [16], with Igbo being the predominant language spoken in the state [17]. The state has a land area of approximately 5,670 square kilometres (2,190 square miles), making it one of Nigeria's smaller states in terms of size [18].

Climate-wise, Ebonyi State has a tropical climate with distinct wet and dry seasons. The wet season, which lasts from April to October, is distinguished by higher rainfall and humidity [19]. The dry season, on the other hand, lasts from November to March and is marked by lower precipitation and higher temperatures. The state's average annual temperature ranges between 26 and 28 degrees Celsius (79- and 82 degrees Fahrenheit) [5]. Ebonyi State's landscape is characterised by undulating plains and hills [15], as well as the presence of several rivers and streams. These natural bodies of water, such as the well-known Cross River, contribute to the state's agricultural productivity while also providing opportunities for fishing and other water-related activities [15].

B. Data and Sources

The optical and infrared bands of Sentinel-2 satellite imagery with 20 m resolution were stacked and reprojected from WGS 1984 to UTM zone 32N for the study area. This enabled land cover detection. Different indices like normalized difference vegetation index (NDVI) were calculated to identify water resources, vegetation, and agricultural areas. The watershed was delineated and slope, elevation, and flow direction data for the study area were extracted from the SPOT 5 digital elevation model (DEM).

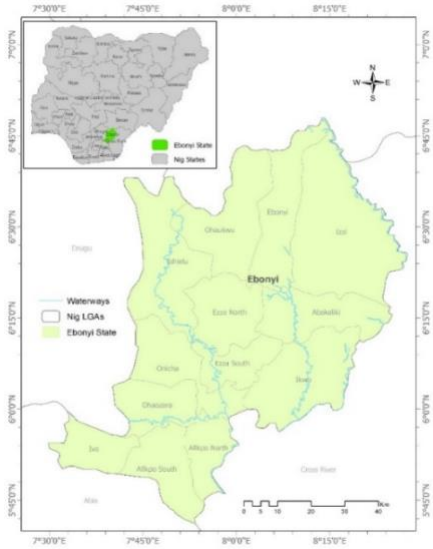

Fig. 1. Map showing the study area Ebonyi state, Nigeria

TABLE 1: DATA SETS

	Data	Variables	Year	Source	Format
1	Basemap	Relief Map	Last updated to 2023/06/12	Esri ArcGIS base map https://esri.com	Raster
2	Satellite Images	Landuse/cover Classification	2018, 2019, 2020, 2021 & 2022	Esri Living Atlas https://livingatlas.arcgis.com/landcoverexplorer/	Raster
4	Administrative boundaries	Nigerian States and Local Government Area	recent	GRID3 https://grid3.gov.ng	Shapefiles
5	Open Street Map (OSM)	Landuse type	Last updated 2023/06/12	OpenStreetMap https://download.geofabrik.de/africa/nigeria.html	Shapefiles
6	SPOT 5	Elevation, slope & hydrology	2010	United States Geological Survey https://earthex	Raster

				plorer.usgs.us .gv	
7	Soil and Geology	Lithology and soil	recent	Nigerian Geological Survey Agency https://ngsa.gov.ng/	Shapefiles

C. *Preprocessing and Data Analysis*

The collected data were Cleaned and preprocessed to remove any errors, outliers, or inconsistencies. Exploratory data analysis was conducted to understand the distribution and characteristics of the data and then Calculations of descriptive statistics for each environmental factor. Utilize the ArcGIS Pro 3.1 software to implement the geostatistical techniques. collected data were imported into a spatial database. Parameters were set up for each geostatistical technique (EBK and IDW) based on the data characteristics and research objectives see Fig.3. Geostatistical techniques were applied to generate maps and visualisations showing the spatial variability of the suitability factor for rice production in Ebonyi State.

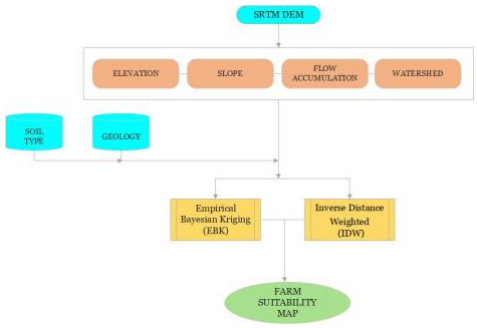

Fig. 2. Analysis flowchart

D. *Empirical Bayesian Kriging (EBK)*

The process of creating a reliable kriging model is made easier by the geostatistical interpolation method known as empirical Bayesian kriging (EBK). This technique combines estimation and prediction by treating parameters as random variables or factors contributing to the suitability of rice farming in the study area that call for conditional prediction based on observed data [24]. Predictive distribution results in EBK predictions.

Kriging formula:

$$Pz(x_o)^{(Z(x_o)|Z=z)} = \int_{D_\beta \times D_{\sigma^2} \times D_\phi} \mathrm{P}z(x_o), \beta, \sigma^2, \phi(Z(x_o), \beta, \sigma^2, \phi|\boldsymbol{Z} = \boldsymbol{z}) d\beta d\sigma^2 d\phi$$

$$= \int_{D_\beta \times D_{\sigma^2} \times D_\phi} \mathrm{P}z(x_o), \beta, \sigma^2, \phi(Z(x_o), \beta, \sigma^2, \phi|\boldsymbol{Z} = \boldsymbol{z}) \boldsymbol{P}\beta, \sigma^2, \phi(\beta, \sigma^2, \phi|\boldsymbol{Z} = \boldsymbol{z}) d\beta d\sigma^2 d\phi \quad (1)$$

The density $\boldsymbol{P}\beta, \sigma^2, \phi(\beta, \sigma^2, \phi|\boldsymbol{Z} = \boldsymbol{z}) d\beta d\sigma^2 d\phi$ is recognized as a Student's t-density when assuming that the prior belongs to the same family as the one described at the end of this section [22]. However, the integral is often challenging to compute.

E. *Inverse Distance Weighted (IDW)*

Inverse Distance Weighted (IDW) interpolation, a deterministic spatial interpolation method, was employed to estimate suitable locations for rice farming in the study area using known rice farm locations and their corresponding weighted values. The IDW interpolation formula (equation 3) estimates the unknown value $\mathcal{X}^*$ as potential locations for rice farms in the study area. The weight $\mathcal{W}$ in the formula represents the inverse distance of a point to each known point value $\mathcal{X}$ used in the calculation.

$$\mathcal{X}^* = \frac{\mathcal{W}_1 x_1 + \mathcal{W}_2 x_2 + \mathcal{W}_3 x_3 + \ldots + \mathcal{W}_n x_{1n}}{\mathcal{W}_1 + \mathcal{W}_2 + \mathcal{W}_3 + \ldots + \mathcal{W}_n} \quad (2)$$

$$\mathcal{X} = \frac{\sum_i^n \frac{w_i}{d_i \beta}}{\sum_i^n \frac{1}{d_i \beta}} \quad (3)$$

III. RESULTS

A. *Soil and Geology*

The soil of the study area in Ebonyi reveals the presence of several soil types, namely Acrisols, Aisols, Cambisols, Gleysols, and Nitisols. Among these, the most dominant soil type is Nitisols, which extends from the northeastern part to the southeastern part of the area. The lithology of Ebonyi showcases a variety of soil types, each possessing unique characteristics that influence their suitability for irrigated rice farming. These soil types include shallow brown sandy shale soil (labelled as "L" on the map), red-brown sandstone soil, red clayey basalt soil, pale brown loamy alluvial soil, and yellowish-red gravelly acid crystalline rocks.

B. *Elevation and Slope*

Digital Elevation Model (DEM) from SRTM was used to generate the elevation and slope map of the study area. The elevation of the study area ranges from 5m to 28 m, areas with higher elevation in the study area are the Northern part and the southern part of the study area, LGA such as Afikpo North and South in the southern part of the study area have a relatively higher elevation same thing is applies to Ohauku, Ishielu LGA which is in the Northern part of the study area, relatively low elevation are in the west and Eastern central of the study areas see fig. 4d. The slope map is calculated in percentage, the slope of the study area ranges from 0% to 48.3%, locations with higher elevation are the areas with high slope percentage, Afikpo North and South constitute the areas with the highest range of slope value while the other location has a relatively low slope percentage value see fig.4f.

C. *Flow Accumulation*

The total flow accumulation data of Ebonyi have a value ranging from 0 to 1,212,583, the area has a very low accumulation with little location across the Ebonyi. The flow accumulation in Ebonyi State is very low, with most areas having a value of less than 1,000. The highest flow accumulation is found in the southeastern part of the state, near the confluence of the Ebonyi River and the Niger River.

The low flow accumulation also contributes to the high rate of soil erosion in the state.

The catchment area of Ebonyi State is divided into 67 catchment areas fig. 4b. Each catchment area is responsible for the collection and treatment of wastewater from a specific area of the state. The southeastern part of the state has the most catchment areas. The central, northeastern, and southwestern parts of the state have smaller catchment areas.

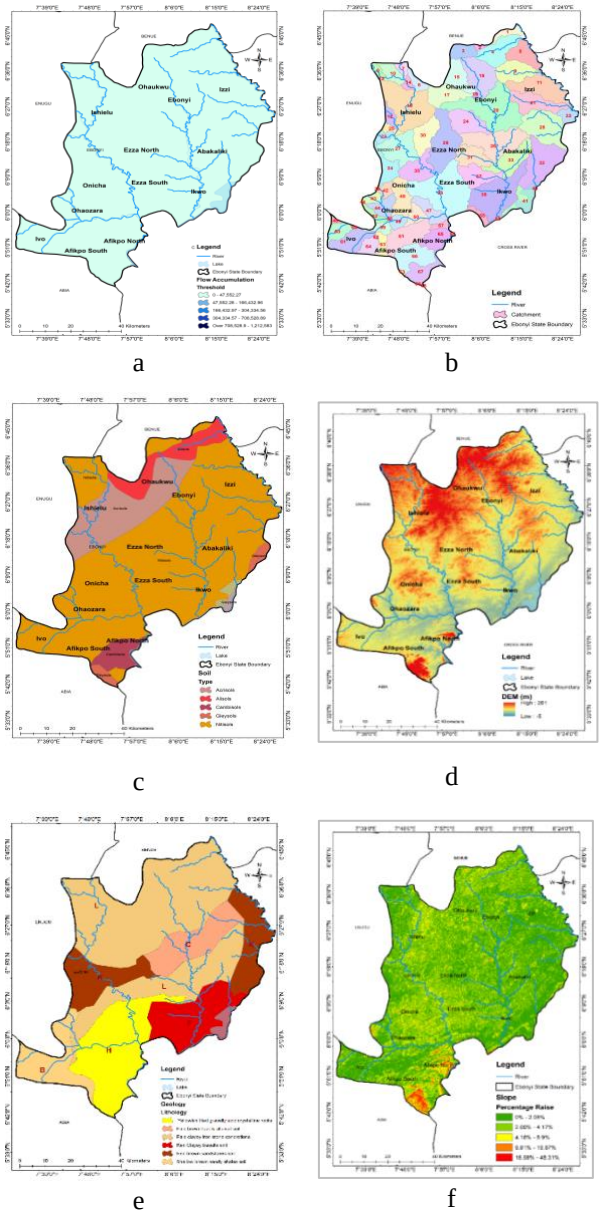

Fig. 3. Equation 4: mapping showing a) Flow accumulation, b) River catchment, c) Soil texture, d) Elevation, e) geology and f) slope of the study area

D. *Suitability Analysis Model Evaluation*

In the process of developing an irrigation model suitability analysis, three regression models were evaluated: Empirical Bayesian Kriging (EBK) and Inverse distance weighted (IDW). These models aimed to predict the relationship between the independent variable, represented and the dependent variable. The evaluation of these models involved assessing their prediction errors using various statistical metrics. For the EBK model, the regression function was determined to be $0.82x + 17.31$. The evaluation was conducted on a dataset comprising 1447 samples. The mean prediction error was found to be 0.03, indicating that, on average, the predicted values were close to the actual values. The root-mean-square error, a measure of the overall model accuracy, was 12.61. The mean standardized error and root-mean-square standardized error were calculated as 0.002 and 0.98, respectively. Additionally, the average standard error was determined to be 12.81. The RBF model yielded a regression function of $0.82x + 17.4$. Similar to the EBK model, the evaluation was performed on the same dataset of 1447 samples. The mean prediction error for this model was 0.08, indicating a slightly larger deviation from the actual values compared to the EBK model. The root-mean-square error was calculated as 14.34, suggesting a moderate level of accuracy. The IDW model was evaluated, with a regression function of $0.82x + 18$. The prediction errors for this 26 model showed a larger mean error of 0.41 and a root-mean-square error of 14.05. These results suggest that the IDW model had the highest deviation from the actual values among the three evaluated models. The evaluation of these models provides insights into their performance for the irrigation model suitability analysis. The EBK model demonstrated relatively smaller prediction errors, indicating a better fit to the data compared to the IDW model see Fig. 4

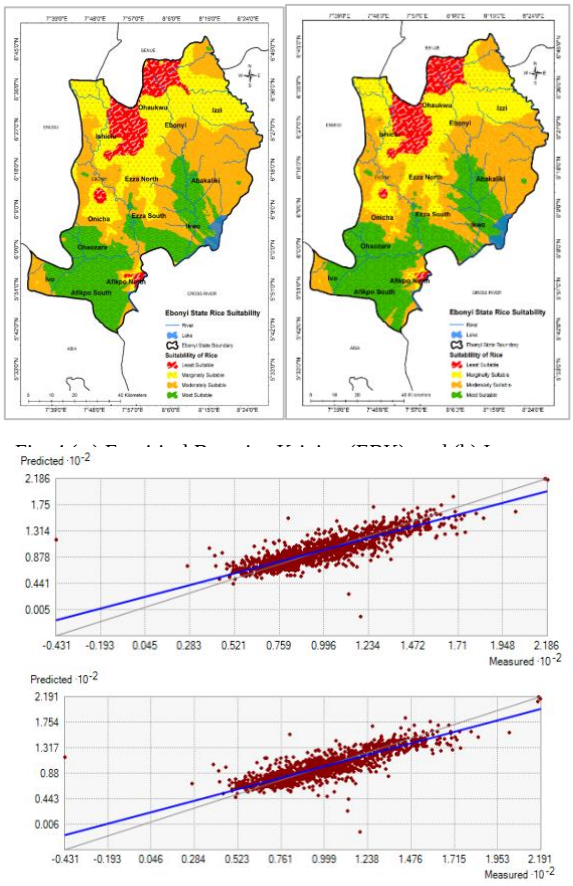

Fig. 5. Predicated values for a) EBK model and b) IDW model

E. Multiple Linear Regression

The multiple linear regression was used to develop models for each environmental factor. Suitability for rice production is the dependent variable and the environmental factors as independent variables. coefficients of the regression models were Determined to quantify the relationship between each environmental factor and rice suitability. The regression equation can be represented as:

$$Rice\ suitability = \beta_o + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_n X_n$$

Where:

$Suitability = Suitability\ for\ rice\ production\ in\ the\ Ebonyi\ state$

$\beta_o, \beta_1, \beta_2 \ldots \beta_n =$ Regression coefficient

$X_1, X_2 \ldots X_n =$ Environmental factors and criteria

i) Factor Hypothesis Testing

From the ANOVA table, the $p - value = 0.0217 < 0.05$ for the *local government assembly (LGA)* factor. The null hypothesis is rejected, thus, concluding that it is statistically significant in the study. This further confirms that the local government assembly (LGA) considered for the study influences flow accumulation on average.

Also, the $p - value = 0.00 < 0.05$ for the *Community* factor, which is statistically significant in the study. The null hypothesis is rejected, so, we can conclude that the selected Community has a great influence on the flow accumulation of rice production.

TABLE 2: ANOVA MODEL SUMMARY

Source of Variation	**Df**	**Sum Sq**	**Mean Sq**	**F value**	**Pr(>F)**
LGA	9	868170	96463	7.432	0.0217
Community	2922	6146859	89544	45.401	0.0000
Water. Source	6	132849	221417	15.992	0.0431
Residuals	3046	7868000	223250		

Finally, the $p - value = 0.0431 < 0.05$ for the *Water source* factor. Thus, The null hypothesis is rejected, so, we can conclude that the selected source of water considered for the rice production has a great influence on the flow accumulation due to the possibilities of run-offs see Table 2.

In addition, no interaction of the three variables above was found to be significant for the study. As a result, the main effects of local government assembly (LGA), Community, and water sources were studied for further analysis.

IV. DISCUSSION AND CONCLUSION

The data analysis reveals that Flow Accumulation, with an average maximum of 160.53 in the Bilonwe Iyokpa ntezi community and Ishielu Local Government Area, signifies robust drainage systems, enhancing the potential for increased rice production. This substantial water supply ensures proper soil nutrient levels, contributing to enhanced rice quality and yield, thereby boosting production and revenue. Conversely, communities such as Amuda, Ledeba, Igwebuike, Ekka, OkpotoI, Azuramura, and Ekwetekwe/Ogbuinyagu, registering an average Flow Accumulation close to zero, depict insufficient water supply or poorly maintained drainage systems, adversely impacting production [17]. Future research could consider studying water sources, local government assembly (LGA), and community as random effects, capturing variations of interest for further analysis. Regarding geology, Ebonyi's diverse lithological types significantly influence the area's suitability for irrigated rice farming. The dominant shallow brown sandy shale soil, while well-draining, requires meticulous water and nutrient management [5]. Other types like red-brown sandstone soil and pale brown loamy alluvial soil offer moderate drainage and excellent water retention, making them conducive for rice cultivation. Conversely, red clayey basalt soil and yellowish-red gravelly acid crystalline rocks necessitate specific management practices to address challenges related to water retention and nutrient availability.

The soil classification in the study area includes Acrisols, Aisols, Cambisols, Gleysols, and Nitisols, with Nitisols being the predominant soil type, Acrisols, despite challenges related to nutrient deficiency and acidity, can be improved through suitable soil amendments [14]. Aisols, characterized by sandy texture and low water-holding capacity, may require additional irrigation and nutrient management for successful rice farming [14]. Cambisols, with better water-holding capacity compared to Aisols, are suitable for irrigated rice cultivation with proper irrigation and fertility management. Gleysols, characterized by poor drainage, may require measures for drainage improvement, creating a conducive environment for rice plants. Nitisols, known for their excellent water-holding capacity, fertility, and organic matter content, emerge as highly suitable for irrigated rice farming, providing an optimal environment for successful rice cultivation. These findings offer valuable insights into the factors influencing rice cultivation suitability in Ebonyi, guiding future agricultural practices and policies [1, 5, 6, 11, 15].

ACKNOWLEDGMENT

Gratitude is extended to Okeke Onyedikachi J from the Department of Mathematics Statistics at the University of New Mexico, Albuquerque NM, USA, Dennis Baidoo, Justice A Frimpong from the Department of Biostatistics at the University of Michigan School of Public Health, University of Michigan Ann Arbor, MI, USA, and Idris Rekiya A from the Department of Remote Sensing and GIS at the Federal University of Technology Akure, Ondo State, Nigeria, for their valuable contributions to this research.

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2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

A Review of Nanotechnology on Agriculture and the Food Industry

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***Abstract*—This review concentrates on the application of nanotechnology in the Agriculture and Food Industry, emphasizing its ability to intricately monitor pivotal regulatory mechanisms in agriculture due to its minute scale. The utilization of nanotechnology presents both promising advancements and potential challenges, offering benefits such as enhanced food quality and safety, reduced agricultural inputs, and improved absorption of nanoscale nutrients from the soil. The agricultural sector must navigate concerns related to sustainability, susceptibility, human health, and fostering a wholesome lifestyle. The integration of nanotechnology in agriculture seeks to minimize pesticide usage, mitigate nutrient losses during fertilization, and increase yields through effective pest and nutrient management. By employing innovative nanotools for rapid disease diagnostics and enhancing plants' ability to fulfill nutritional requirements, nanotechnology emerges as a potential catalyst for strengthening the agriculture and food industries. While the historical use of agrochemicals has boosted agricultural output, it has simultaneously inflicted detrimental effects on soil and aquatic ecosystems, impacting flora, fauna, and the health of individuals consuming chemically treated food. Nanotechnology offers diverse applications in agriculture, including specialized solutions such as nano fertilizers and nano pesticides for precise monitoring of products and nutrient levels. These innovations aim to enhance productivity without compromising soil and water integrity, providing defense against various insects, pests, and microbial diseases. Recent market trends witness the emergence of "nano-food packaging," utilizing nanoparticles in the manufacturing of food packaging materials. Despite the growing prevalence of nanoparticles in food packaging, consumer perceptions, attitudes, and acceptance are influenced by safety concerns. The evolving landscape of nanotechnology in agriculture and food industries underscores the importance of addressing these safety considerations to fully harness the potential benefits while ensuring public confidence and well-being.**

Keywords—Nanotechnology, nanobiosensors, nanoemulsions, agriculture, food packaging

I. INTRODUCTION

The production of raw materials for the food and feed industries plays a constant and pivotal role in ensuring the stability of the agriculture industry [1]. As Johnston and Mellor (1961) pointed out, this importance is underscored by global population growth, the depletion of natural resources such as arable land, water, soil quality, and air quality, and the stagnation in agricultural progress [1].

The evolution of agriculture represents a crucial moment in our efforts to eradicate poverty and hunger, a situation that must be addressed urgently [1]. To achieve this, bold steps are required to foster agricultural development, especially considering that a significant portion of the world's population resides below the poverty line, predominantly in rural and tropical regions where conventional agricultural practices may not be as effective [1].

Nanotechnology operates on a nanometer scale, dealing with atoms, molecules, or macromolecules within the range of approximately 1 to 100 nm, enabling the creation and utilization of materials with environmentally friendly properties [2].

Nanomaterials are characterized by having one or more dimensions within the 1-100 nm scale, which allows for the unique observation and manipulation of matter at the nanoscale [3]. These materials exhibit distinctive properties, differing from their macroscale counterparts' due to their high surface-to-volume ratio and novel physiochemical characteristics, such as color, solubility, strength, diffusivity, toxicity, magnetism, optics, and thermodynamics, among others [2, 3].

Nanotechnology opens up a broad spectrum of possibilities for developing systems, materials, or structures with innovative qualities across various industries, including food, medicine, agriculture, and more [2]. In 2017, researchers began exploring ways to enhance food quality and distinctiveness while preserving the nutritional value of products, driven by growing consumer concerns regarding food quality and health benefits [4].

The demand for nanoparticle-based products in the food sector surged as many of these products contained essential components and demonstrated non-toxic and low carcinogenicity properties [4]. This increased demand has facilitated the integration of nanoparticle-based materials into the food industry [4].

While nanotechnology has already led to significant breakthroughs in industries like microelectronics, aerospace, and pharmaceuticals, its application within the food industry remains somewhat limited and merits further attention [5].

In conclusion, prioritizing innovation, addressing agricultural poverty, and enhancing the nutritional aspects of food production are of paramount importance [1]. Therefore, the adoption of cutting-edge technologies like nanotechnology is crucial for achieving sustainable agricultural expansion [1].

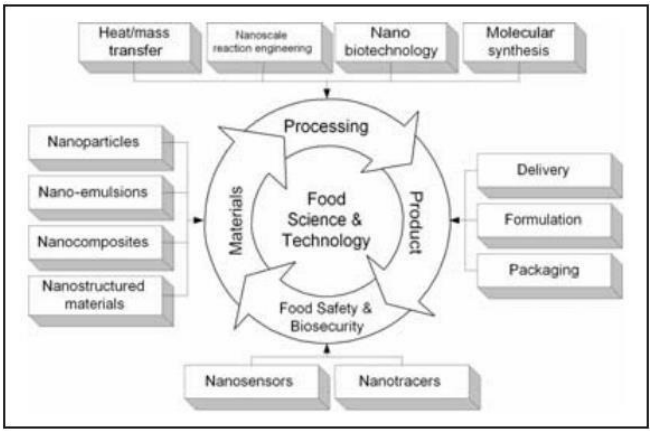

Fig. 1. Nanotechnology in food science: a matrix of applications

Food and beverages are subject to various forms of packaging, serving essential functions such as safeguarding and preserving the products, maintaining their quality and safety, promoting sustainability, and minimizing food wastage [1]. Innovative food packaging materials and technologies have emerged to fulfill these roles and play a pivotal role in ensuring safe and nutritious food supply chain management.

The introduction of nanotechnology, which involves materials manufactured and utilized within the nanometer scale range (up to approximately 100 nm in one or more dimensions), has opened up new avenues for enhancing food contact materials and improving the food and beverage industry [2]. Notably, the food and beverage industry has eagerly embraced nanotechnology, recognizing its potential benefits [6].

Numerous leading food companies worldwide have actively explored the utilization of nanomaterials in food production and packaging [6]. Nanotechnology offers comprehensive and innovative solutions spanning food manufacturing, processing, packaging, and supply chain management, leading to improvements in food quality, safety, and health benefits [7, 8].

Two pivotal categories facilitating the effective implementation of nanotechnology in the food industry include food nanostructured ingredients and food nanosensing [8]. Nanostructured ingredients play a crucial role in various aspects of food processing, serving as additives, carriers for nutrient delivery, agents to prevent caking, antibacterial components, and enhancers of the mechanical strength and durability of packaging materials [8].

Food nanosensing plays a pivotal role in enhancing food quality, safety, and sustainability evaluation [8]. However, it's essential to note that there are certain negative aspects associated with nanotechnology that warrant consideration [8].

While agrochemicals have increased agricultural productivity, they have also had adverse effects on soil, aquatic ecosystems, flora, fauna, and human health due to chemically grown food consumption [9]. The advent of nanoagrochemicals, including nano-pesticides, nano-fertilizers, and nanosensors, offers significant potential benefits, such as increased solubility, improved bioavailability, targeted delivery, and controlled release [9]. This has the potential to lead to efficient fertilizer dosages, better vector and pest management, reduced chemical pollution, minimized natural resource depletion, and ultimately enhanced agricultural productivity [9].

Numerous regulatory bodies and institutions, including but not limited to the Institute for Occupational Safety and Health, the U.S. Food and Drug Administration (FDA), the Health and Consumer Protection Directorate of the European Commission, the World Organization for Standardization, and the Organization for Economic Cooperation and Development, have issued guidance documents addressing the potential risks linked to nanomaterials [10].

Additionally, the U.S. Environmental Protection Agency implemented reporting and recordkeeping requirements related to nanotechnology in 2015, focusing on the functionality and applicability of food nanotechnology and agricultural needs under the Toxic Substances Control Act Section 8(a) [10].

II. NANOTECHNOLOGY IN AGRICULTURE

Nanotechnology holds great promise as an innovative approach to revolutionizing sustainable agriculture, with precision farming being a key application [12]. Precision farming aims to enhance crop yield by monitoring environmental factors and applying targeted actions tailored to specific conditions.

In the realm of agriculture, nanotechnology can significantly contribute to productivity by enabling the controlled release of nutrients and monitoring water quality and pesticide use, all essential for sustainable agricultural development [1].

Several properties of nanoparticles (NPs), beyond their size, influence their toxicity, including chemical composition, shape, surface structure, surface charge, behavior, and particle aggregation or disaggregation [1]. These properties are critical considerations when working with engineered NPs.

Nanotechnology research has become an integral and vital component of sustainable development in the agriculture and food industries. Applications such as nanotubes, fullerenes, biosensors, controlled delivery systems, and nanofiltration have found relevance in the agri-food sectors [2].

Nanosensors, a subset of nanotechnology, play a crucial role in agriculture by enabling environmental monitoring for soil and water contamination. Biosensors, electrochemical sensors, optical sensors, and other nano-detection technologies are instrumental in detecting heavy metals in trace amounts [13].

Nanomaterials not only catalyze the degradation of waste and toxic substances but also enhance the efficiency of microorganisms involved in bioremediation, which is the process of using living organisms to remove toxins from agricultural soil and water [1].

Nanofertilizers, a type of nanomaterial, supply essential nutrients to growing plants, promoting their growth and increasing crop yields. These nanofertilizers are categorized into three groups based on the nutritional needs of plants: macro-nano fertilizers, micro-nano fertilizers, and nanoparticulate fertilizers and improve the bioavailability of essential elements needed in small quantities for various metabolic processes in plants, leading to improved plant growth and nutritional quality [14]

Macronutrient nanofertilizers cater to the nutrient requirements of plants that are needed in larger quantities, such as nitrogen (N), phosphorus (P), potassium (K), magnesium (Mg), sulfur (S), and calcium (Ca) [14].

The overuse of conventional mineral fertilizers and harmful pesticides has resulted in pollution and health concerns. Nanotechnology offers solutions to these problems by providing high-performance nanomaterials. Nano fertilizers with improved release and targeted delivery efficiency encompass various essential nutrients like N, P, K, Fe, Mn, Zn, Cu, Mo, and carbon nanotubes [14].

Nanoparticulate fertilizers, including nanoparticles like TiO_2, SiO_2, and carbon nanotubes (CNTs), exhibit growth-promoting activity in plants [14].

While major chemical corporations have yet to develop agricultural fertilizers, nano fertilizers are readily available on the market. They may contain nanoscale materials such as titanium dioxide, silica, zinc, iron, and core-shell quantum dots (QDs) composed of various metals. This technology holds the potential to enhance biomass productivity and improve the utilization of biomass and organic waste through interdisciplinary advancements in ecology, biology, biodiversity, materials science, biotechnology, and engineering [1]. Some available nano fertilizers in the markets are Nano-GroTM – Plant growth regulator and immunity enhancer, Nano Green - Extracts of corn, grain, soybeans, coconut, and palm, Nano-Ag Answer – Microbes, sea kelp, and mineral electrolytes, Biozar – Combination of organic materials, micronutrients and macromolecules.

III. NANO PESTICIDES

Future research should prioritize exploring how nanomaterials can be harnessed to simultaneously protect crops and ensure sustainable food production. Agricultural regions frequently face the persistent issue of insect pests and the consequential damage they inflict, underscoring the imperative need to tackle these challenges. Nanoparticles (NPs) could emerge as a game-changer in pest and infection management. The development of nanoencapsulated pesticide formulations with controlled release properties, improved solubility, specificity, permeability, and stability holds great promise in this regard [15].

The effective utilization of nanotechnology in integrated pest management relies on controlled pesticide delivery, enhancing activity at lower concentrations, and monitoring pesticide interactions with the environment in an eco-friendly manner [16].

IV. NANOTECHNOLOGY IN FOOD PROCESSING

Nanotechnology is advancing the development of food components containing nanostructures, offering the potential for enhanced aroma, taste, and consistency [8]. As demonstrated by Pradhan et al. (2015), nanotechnology can extend the shelf life of various food components and reduce food waste resulting from microbial contamination [23].

Nanotechnology significantly impacts various aspects of food and agriculture systems, including food security, safety, disease management, novel delivery methods for disease treatment, molecular and cellular biology innovations, novel materials for pathogen detection, and environmental sustainability [23]. Several notable applications of nanotechnology in the food industry include:

Enhanced Food Safety: Nanosensors are employed for the detection of pathogens and contaminants in food, increasing the security of food production, processing, and distribution.

Product Traceability: Nanotechnology facilitates the tracking of individual food product shipments and provides historical and environmental data, contributing to supply chain management.

Smart/Intelligent Systems: The integration of sensing, localization, reporting, and remote control within food products and packaging represents a significant advancement that enhances the efficiency and safety of food processing and transportation.

Novel Delivery Systems: Leveraging nanotechnology, novel delivery systems such as encapsulation, emulsions, biopolymer matrices, and association colloids are created, providing efficient mechanisms for delivering additives and active ingredients in food products.

Nanosensors for Detection: The application of nanosensors proves invaluable in identifying pollutants, mycotoxins, and microbes at different stages of food processing, contributing to robust measures for ensuring food safety.

Enhanced Bioavailability: Nanocarriers play a crucial role in transporting food additives within food items without compromising their fundamental characteristics. This enables improved bioavailability, with particle size emerging as a critical factor, where submicron nanoparticles exhibit more efficient absorption by specific cell lines compared to larger micro-particles [23].

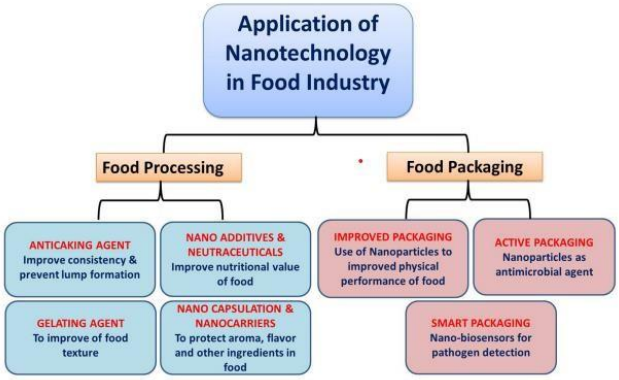

Fig. 2. Diagrammatic representation of the use of nanotechnology in many food-related industries [11].

Bacterial spoilage poses a significant challenge across the entire food production, processing, transportation, and storage chain. To address this issue, recent developments in nanotechnology have shown great promise in combating food spoilage and extending the shelf life of products. Nanomaterials, including various metals and metal oxides, have been suggested as effective antimicrobial agents for this purpose [11].

V. NANO ENCAPSULATION

The term "nanoencapsulation" encompasses the cutting-edge technique of encapsulating substances at the nanoscale level, employing films, layers, and coatings to envelop food or other substrates [24]. This encapsulating layer forms a transparent, protective covering on the molecules or chemicals within food, preserving their integrity and properties.

Nanoencapsulation is crucial in creating delivery systems designed to carry, protect, and deliver functional food ingredients precisely to their intended sites of action. Innovative research in nanotechnology is reshaping applications in biosciences and engineering, marking a significant departure from traditional nanotechnology applications.

The process involves compacting substances on a miniature scale through methods such as nanocomposite formation, nano emulsification, and nano structuration, culminating in the creation of the final product. Nanoencapsulation serves as a vessel for transporting functional ingredients to their designated sites of action [24].

It fulfills several essential functions:

Protection and Isolation: Nanoencapsulation shields functional ingredients from chemical or biological reactions, preventing degradation during processing, storage, and utilization.

Controlled Release: Nanoencapsulation systems are capable of regulating the release of functional ingredients, ensuring they are delivered precisely when and where needed [24]. Various encapsulation methods are employed in nanotechnology:

Spray Drying: This cost-effective method is commonly used for encapsulation and is suitable for a wide range of applications.

Spray Chilling: Particularly useful for protecting water-soluble cores and sensitive cores that are temperature sensitive.

Extrusion: Primarily employed for encapsulating flavors and volatile cores within glassy matrices.

Fluidized Bed Coating: Utilized for achieving fine control over the release properties of the core.

Inclusion Complexation: Effective for encapsulating flavors and lipophilic nutrients.

Coacervation: Suitable for entrapment of high loadings of cores, commonly used in encapsulating flavors and various nutrients [24-27].

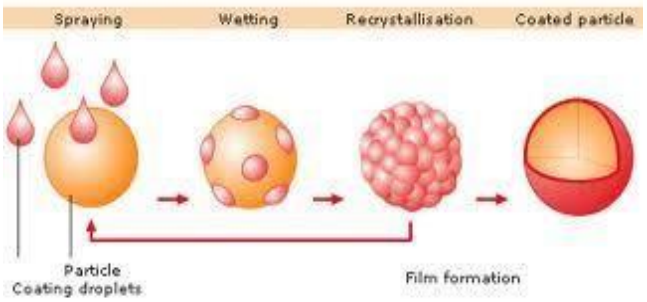

Fig. 3: Encapsulation in food

The selection of the appropriate wall material is a critical and sophisticated process, as it profoundly impacts the encapsulation efficiency, precision, and stability of microcapsules. The ideal wall material should possess the following key characteristics:

Non-Reactivity with the Core: The chosen wall material should not react with the core substance it encapsulates. This ensures that the core's integrity and properties remain unaltered during encapsulation.

Effective Core Encapsulation: The material should have the ability to seal and encapsulate the targeted core efficiently within the capsule. This ensures that the core is well protected.

Protection Against Adverse Conditions: The wall material should provide maximum protection to the core against adverse conditions, including environmental factors such as temperature, humidity, and light. This protection is crucial for preserving the core's quality and effectiveness.

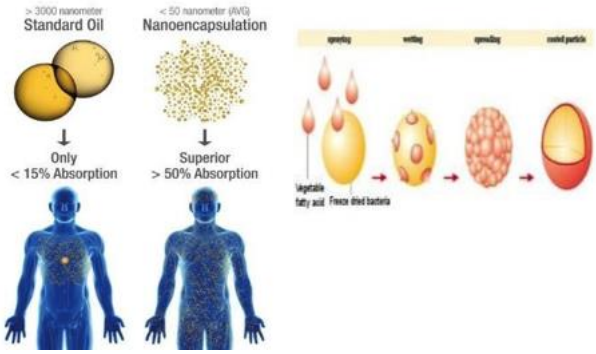

Fig. 4. Nanoencapsulation Vs Human Absorption

Sensory Attributes: In applications related to food, the wall material should not impart unpleasant tastes or aromas to the encapsulated product. This is essential for maintaining the sensory attributes of the final product.

Economic Viability: The selected material should be economically viable, as cost-effectiveness is a significant consideration in large-scale production.

Eco-Friendly: Environmental considerations are vital. The wall material should be eco-friendly, with minimal environmental impact throughout its lifecycle.

The careful consideration of these characteristics ensures that the chosen wall material aligns with the specific requirements and objectives of the microencapsulation process, whether it be for food applications, pharmaceuticals, or other industries [24].

VI. NANOBIOSENSORS

Nanosensing technology, employing the use of biological elements, represents a cutting-edge and highly desirable method for the rapid analysis of pesticides. It serves as a promising and convenient approach for detecting contaminants in food and addressing environmental safety concerns. This technology offers a quick, cost-effective, field-deployable solution with heightened sensitivity, enabling the detection and quantification of up to four targets by converting target recognition into physically observable signals, such as optical, electrical, and magnetic signals [28].

Nanosensors, at their core, are typically microscopic or submicroscopic in size and are designed as either chemical or physical sensors using nanoscale components. There are two primary categories of nanosensors:

Active Nano Sensors: These sensors can transmit signals that can be received remotely. They are instrumental in real-time data collection and communication.

Passive Nanosensors: Passive nanosensors operate based on observations and typically manifest changes in color, opacity, or fluorescence. They are used to detect and recognize the presence of nanomaterials or molecules at the nanometer scale or smaller.

The versatility and sensitivity of nanosensors make them invaluable tools for various applications, including the rapid analysis of pesticides and the monitoring of environmental and food safety [28].

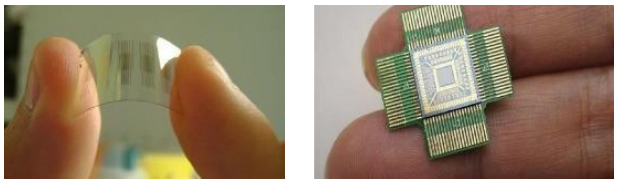

Fig. 5: Nano sensors

Nanoscale biosensors have emerged as powerful tools for advanced pathogen detection and diagnosis. They also play a pivotal role in delivering bioactive ingredients and substances within food products, contributing to our understanding of food materials at the nanoscale. The integration of nanotechnology into biosensors harnesses the unique physical and chemical properties of nanomaterials, driving the evolution of biosensor technology [29].

Biosensors yield reliable sensor devices that enable effective and convenient detection and pollution control. Various biological elements are employed in the nanotechnology field for pesticide measurement and detection, including enzymes, antibodies, nucleic acids, aptamers, and whole cells. [28].

While nano-biosensors have shown significant promise in pesticide detection, some types face limitations in practical applications, particularly in the context of food quality and safety. It is crucial to extend their usage to enhance the utility of nano-biosensors in pesticide analysis. Additionally, innovative methods must be developed to enhance the reusability of nanobiosensors, further improving their practicality and efficiency [28].

VII. NANO FOOD PACKAGING

In the food industry, ensuring quality, safety, freshness, taste, texture, and other critical factors across the entire supply chain necessitates effective packaging and labeling by producers [33]. The development of smart packaging solutions that provide valuable information remains a challenging yet crucial task for both researchers and producers.

Enhancing the barrier properties of food packaging is essential to preserve freshness and protect food from factors like light exposure, oxygen ingress, humidity, contamination, odor absorption, and flavor loss. The industry's growing shift toward lightweight materials and the need for extended shelf life, improved convenience, and reduced food waste has led to a demand for thin and lightweight materials with exceptional barrier properties.

Nano-thin coatings and nanocomposites, which combine polymers with nanoparticles, have proven effective in enhancing barrier performance. For example, vacuum-deposited aluminum coatings, which can be as thin as 50 nm, qualify as nanomaterials due to their nanoscale dimension in one direction and are commonly used as barrier materials for packaging snack foods, confectionery, and coffee [34].

To monitor the oxidation process in food, packaging materials with embedded "nanosensors" have been developed and are employed in the food industry. The principle is straightforward: when oxidation occurs within the food packaging, NP-based sensors detect and signal color changes. This technology has found success in milk and meat packaging applications.

Nanoparticles exhibit superior barrier properties against gases like oxygen and carbon dioxide, making them valuable for food packaging. They allow for better control of carbon dioxide levels within bottles and packaging made with nanocomposites, minimizing CO_2 loss, reducing packaging weight, and extending shelf life, among other benefits [1]. In the realm of packaging, there are two main approaches:

Passive Packaging: Traditional packaging primarily serves as a barrier, protecting food from external factors and preserving its quality.

Active Packaging: In active packaging concepts, the packaging itself plays a role in altering the food's nature or the composition of the atmosphere surrounding the food within the package. This approach offers opportunities for innovative solutions that go beyond traditional protective functions [33].

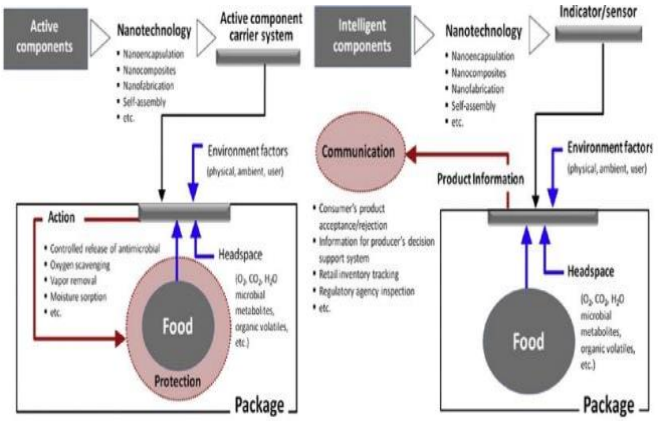

Fig. 6. Development of nanotechnology and its application in active and intelligent packaging

Nanocomposite - packaging that incorporates nanoparticles to enhance biodegradability, barrier characteristics, and physical performance. [34]

Nanocoatings-improve the barrier qualities of packaging by adding nanoparticles to the surface (on the inside or outside, or sandwiched between layers in a laminate) [34]

Surface biocides-utilizing nanoparticles with antibacterial effects on the surface of the packaging [34]

Active packaging-incorporating nanoparticles with purposeful release into- and the subsequent impact on the packaged food that has antibacterial or other qualities (e.g., antioxidants) [34]

Intelligent packaging-using nanosensors to track and report on the food's condition [34].

VIII. NANOEMULSIONS

Nanoemulsions are characterized by their extremely small particle sizes, making them particularly suitable for various applications in the food industry. Their unique attributes, including small dimensions, a high surface area, and resistance to physical and chemical changes, make them highly desirable [35, 36]. In the food business, food-grade nanoemulsions are extensively utilized for targeted delivery systems, effective encapsulation of bioactive ingredients, and improved digestibility [3, 36].

Compared to traditional emulsions, nanoemulsions offer several advantageous properties, enhancing their utility in the food industry. Creating nanoemulsions typically involves two main methods: dispersion or high-energy emulsification techniques and condensation or low-energy methods.

Dispersion or High-Energy Emulsification: This method is commonly employed for nanoemulsion formation, producing droplet sizes ranging from 20 to 200 nm with narrow size distributions.

Condensation or Low-Energy Methods: These techniques are also used effectively to form nanoemulsions. Both methods yield droplet sizes within the nanometer range [37].

Enhancing the durability of nanoemulsions can be achieved by introducing substances like emulsifiers, compounds that slow down the process of droplet growth, substances that increase the density, or additives that modify the texture. These nanoemulsions, made from food-grade components, are increasingly utilized to encapsulate biologically active lipids like Omega-3 fatty acids and polyunsaturated fatty acids. Typically, high-pressure valve homogenizers or microfluidizers are utilized to create emulsions with droplets smaller than 100 to 500 nm, commonly referred to as "nanoemulsions."

The extensive literature available on the preparation, characterization, and applications of nanoemulsions reflects their long-standing presence in research and development [39].

Functional food components are often incorporated within the realm of nanoemulsions. The focus extends beyond just the tiny droplets themselves; it encompasses the properties of these droplets, the interfacial region, and the continuous phase. Functional components are encapsulated within these droplets, and the characteristics of the interfacial layer surrounding them play a crucial role in their performance [39].

The use of multiple emulsions offers a means to create delivery systems with exceptional encapsulation and delivery capabilities. Two fundamental examples of multiple emulsions are oil-in-water-in-oil (O/W/O) and water-in-oil-in-water (W/O/W) emulsions. These systems allow for the encapsulation of functional food components within the inner water phase, the oil phase, or the outer water phase, enabling the creation of a single delivery system containing multiple functional components [5].

These delivery systems typically consist of oil droplets (the core) surrounded by nanometer-thick layers (the shell) composed of various types of polyelectrolytes. These layers are formed using a layer-by-layer (LbL) electrostatic deposition method involving the sequential adsorption of polyelectrolytes onto the surfaces of oppositely charged colloidal particles.

Nanoemulsions have found a wide range of applications, notably in improving the solubility of bioactive compounds like phytosterols, known for their cholesterol-reducing properties and the potential to lower the risk of coronary heart diseases. Additionally, nanoemulsions enhance the solubility of compounds such as lycopene, a carotenoid pigment abundant in tomatoes and other red fruits and vegetables, recognized for its positive impact on conditions like prostate cancer and cardiovascular diseases [38, 41].

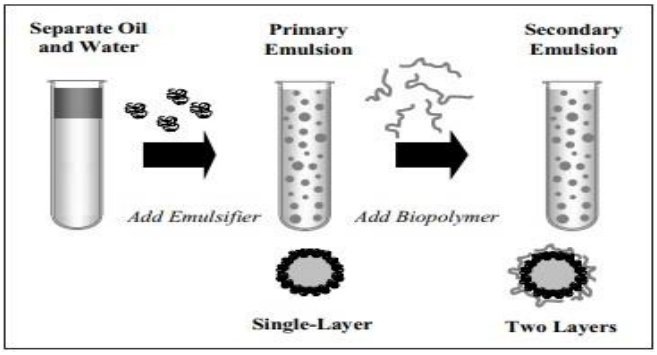

Fig. 7. A schematic representation of the formation of several nanolayers around particles [5].

Furthermore, nanoemulsions have been a subject of exploration for their ability to enhance food digestibility, aiding in the efficient absorption of nutrients by the gastrointestinal tract. This attribute proves particularly beneficial for natural extracts like β-Carotene, which can now be harnessed more effectively [42].

Nanoemulsions have also played a vital role in addressing the challenge of low bioavailability associated with certain naturally occurring bioactive compounds. By utilizing nanoemulsions, researchers have improved the systematic pharmacological effects of oil-soluble vitamins, exemplified by the enhanced oral bioavailability and therapeutic impact of alpha-tocopherol, among others [38].

However, as we delve deeper into the realm of nanotechnology's applications in various industries, including food and agriculture, it becomes essential to consider safety concerns. One notable concern revolves around the potential migration of nanoparticles from packaging materials into food products. Existing regulations primarily cover conventional substances, leaving some nanomaterials unregulated even when their migration levels fall below legal limits. Consequently, public apprehension regarding potential health risks associated with nanomaterials persists until comprehensive safety assessments are conducted and validated [15].

Despite the myriad advantages of nanotechnology in fields such as food production, agriculture, and medicine, safety issues related to nanomaterials cannot be underestimated. While many nanomaterials were previously deemed Generally Recognized as Safe (GRAS) substances, recent research highlights the need for an in-depth investigation into the potential risks and adverse health effects of their nano counterparts. The smaller size of nanomaterials increases the possibility of bioaccumulation within organs and tissues, necessitating a more thorough examination of their safety profile [8].

IX. Conclusion

Nanotechnology stands as a groundbreaking and promising frontier in the field of agriculture, offering sustainable solutions to traditional farming practices through the development of nano fertilizers and nano pesticides. These nanoenabled tools have showcased their potential to enhance crop yield, reduce environmental impact, and ensure food security.

Nano biosensors, with their attributes of selectivity, sensitivity, and rapid detection, present an appealing avenue for pesticide detection. Enzyme-based biosensors, among various bio elements, have emerged as the preferred choice for toxin detection in the agricultural context. Nevertheless, the widespread incorporation of nanotechnology in the food industry, especially in the realm of food packaging, brings forth challenges concerning consumer and environmental safety. Ambiguities surrounding the safety of nanomaterials have impeded both market acceptance and regulatory endeavors.

The uncertainty arises from the fact that toxicity levels for many nanoparticles are not clearly defined, constraining their usage due to the absence of comprehensive risk assessments and an understanding of their potential implications on human health. To fully exploit the potential of nanotechnology, it is imperative to address these challenges. The development of a comprehensive database and an effective alarm system, coupled with international cooperation in regulating and legislating nanotechnology, are essential steps forward. These measures will not only ensure the responsible use of nanomaterials but also pave the way for their broader application across diverse industries.

In the era of nanotechnology, collaboration among researchers, policymakers, and industry stakeholders is paramount. With the right safeguards in place, nanotechnology can usher in a new era of sustainable agriculture, improved food safety, and enhanced environmental stewardship. It is a technology with the potential to reshape our world, but its responsible and ethical deployment is crucial for a brighter and more sustainable future.

Acknowledgment

I am highly indebted to the Department of Agriculture and Food Technology, the University of Vocational Technology, Rathmalan, and my classmates and people who have willingly helped me out. I would like to express my profusely thanks to my parents and my supervisor for their guidance and supervision as well as for providing necessary information regarding the project & also for their support in completing the project.

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2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

Applications of Aluminosilicate Zeolites for Sustainable Agriculture and Aquaculture Development

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***Abstract*—Zeolites, crystalline aluminosilicate minerals, have emerged as powerful candidates for promoting sustainability in both agriculture and aquaculture. Their exceptional ion-exchange capacity, surface area, and adsorption properties make them invaluable tools in addressing critical challenges in these sectors. In sustainable agriculture, zeolites contribute significantly to nutrient management. They enhance soil fertility by retaining and slowly releasing essential nutrients, reducing the need for excessive chemical fertilizers. Moreover, zeolites improve soil structure, water retention, and microbial activity, fostering healthier soils and reducing erosion risks. In the realm of aquaculture, zeolites play a crucial role in water quality management. They effectively adsorb ammonia and other harmful compounds, ensuring a healthier environment for aquatic organisms. Additionally, their ion-exchange properties can supply essential minerals to support the growth of aquatic species. By minimizing nutrient loss, mitigating pollution, and promoting resource-efficient practices, zeolites offer innovative solutions to meet the growing demand for sustainable agriculture and aquaculture practices while minimizing environmental degradation, thus contributing to a more sustainable and resilient future.**

Keywords—Agriculture, aquaculture, sustainability, water purification, zeolite

I. INTRODUCTION

The global challenges of sustainable agriculture and aquaculture have become increasingly famous in the face of a growing population and environmental concerns. To address these complex issues, innovative solutions are required, and one such solution that has gained prominence is the use of aluminosilicate zeolites. These honeycomb-frameworked [1] crystalline microporous materials [2] have demonstrated remarkable versatility and potential in transforming traditional agricultural and aquacultural practices towards more sustainable and environmentally friendly approaches. Zeolites, an economically accessible mineral [3], possess a diverse array of applications spanning environmental, medical, agricultural, and wastewater treatment domains. Their exceptional utility primarily stems from their ion exchange capabilities, porous nature [1], high adsorption capacity, and intricate three-dimensional framework. These minerals can be found naturally as products of volcanic processes [4] or can be intentionally manufactured through synthetic procedures [5]. Natural zeolites are created through a lengthy geological process. It begins with volcanic activity [4], where ash and tuff [4] release silica and aluminum-rich materials. When these materials interact with groundwater or surface water, a hydrothermal alteration process is initiated, allowing the leaching of soluble components and the deposition of new minerals, including zeolites. Under specific temperature and pressure conditions below the Earth's surface, crystalline zeolite structures form over millions of years. Once formed, zeolites are mined from these deposits and utilized for their diverse industrial, agricultural, and environmental applications, their properties shaped by their geological origins. Given their valuable attributes, the use of zeolites has garnered significant attention within the scientific community, particularly in the context of environmental applications. Some common natural zeolites are Analcime [6], Chabazite [6], Clinoptilolite, Heulandite [7], and Phillipsite [3], and over 200 synthetics [1] zeolites have been created using an elongated crystallization technique of a silica-alumina gel [8] in the presence of alkalis and organic templates [9]. Artificial synthesis of zeolites involves mixing aluminium and silicon sources to create a gel [10, 8], adding structure-directing agents to guide zeolite formation, subjecting the mixture to a hydrothermal treatment [8] at elevated temperatures, crystallizing [11] the zeolite structure, washing and drying the resulting material, and obtaining the final synthetic zeolite. The choice of structure-directing agents and reaction conditions determines the specific type of zeolite formed. Synthetic zeolites have versatile applications in various industries due to their adsorption, separation, and catalytic properties. Theoretically, many more of these structures could still be developed.

The effectiveness of the mechanism of zeolitic action in various applications hinges on their unique structure [1]. Zeolites' lattice of interconnected channels and cavities, create a porous network that facilitates the ingress of various ions as well as micron-sized molecules. As illustrated in Figure 1, they are hydrated aluminosilicates with fully cross-linked open framework structures made up of corner-sharing SiO_4^{4-} and AlO_4^{5-} tetrahedra [2]. This network also serves as a molecular sieve, selectively filtering molecules based on their size, polarity, and shape. As a result, zeolites excel at the adsorption and filtration of a wide array of substances that come into contact with them. This distinctive zeolite structure, characterized by its high porosity, significantly enables the efficient adsorption of charged elements. To balance the negative charges within zeolite frameworks, mono- or divalent cations such as Na^+, K^+, Ca^{2+}, Mg^{2+}, and others are commonly incorporated and can be substituted or replaced with different cations. Furthermore, zeolites are known for their rapid regeneration [1] capabilities, making them highly effective in removing and replacing a broad

spectrum of charged species, including but not limited to ammonia, heavy metals [12], pesticides [13], odors, radioactive cations, and various other toxins.

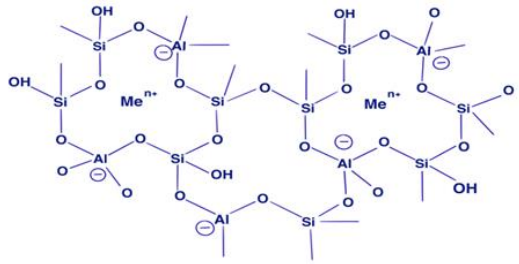

Fig. 1. Honeycomb shaped structural framework of zeolites containing aluminium, silicon, oxygen and hydrogen.

In recent years, the critical role of aluminosilicate zeolites in promoting sustainability in agriculture and aquaculture has attracted significant attention from researchers, policymakers, and industry leaders. Their unique properties, which include having a high surface area, high cation exchange capacity(CEC) [14], and selective adsorption capabilities, make them valuable tools in optimizing nutrient management, improving soil health [15], and enhancing water quality in these crucial sectors. The urgency of these challenges cannot be overstated. Population growth, climate change, and resource depletion have placed immense pressure on global food production systems. Simultaneously, concerns about soil degradation, water pollution [16], and the ecological impact of agriculture and aquaculture practices have intensified. In response to these interconnected challenges, researchers have turned to innovative materials like aluminosilicate zeolites to forge a path toward sustainable solutions.

This review-based exploration aims to delve into the multifaceted applications and benefits of aluminosilicate zeolites in the realms of sustainable agriculture and aquaculture. By elucidating their contributions to soil enrichment, nutrient retention, water purification, and overall environmental stewardship, we embark on a journey to understand how these zeolites can play a pivotal role in addressing the pressing challenges of ecological sustainability in our ever-changing world.

II. Zeolites for Multidisciplinary Sustainability

Zeolites, with their remarkable properties and diverse applications, are increasingly recognized as major contributors to overall sustainability. Their impact spans across various sectors, including agriculture, water treatment, industry, and environmental remediation. In the realm of agriculture, zeolites play a critical role in promoting sustainable practices. Their properties enhance nutrient management, reducing the need for excessive chemical fertilizers while minimizing nutrient leaching, thus making agricultural processes more efficient and environmentally friendly. Additionally, zeolites' water-retaining properties [1] help conserve water resources, a vital component of sustainable farming that becomes increasingly significant in regions facing water scarcity. Zeolites also reduce the dependency on synthetic chemicals, leading to more sustainable and eco-friendly farming practices [1]. By decreasing the need for chemical pesticides and fertilizers, zeolites contribute to reduced environmental and health risks associated with their use.

Moreover, zeolites are instrumental in water purification and treatment processes, significantly improving water quality and safeguarding ecosystems. Their ability to adsorb heavy metals [12], ammonia [17], and various contaminants from water sources contributes to providing a safe and sustainable water supply for both human consumption and industrial use. This is especially crucial in an era marked by growing concerns about water pollution and scarcity. Furthermore, they have been proven effective in the remediation of contaminated soil and groundwater, playing a crucial part in the cleanup of polluted sites and environmental conservation. Their use aids in minimizing the release of harmful substances into the environment, thereby contributing to sustainability.

Their role extends beyond agriculture and water treatment. They are pivotal in various industrial applications, such as petrochemicals [18] and catalysis [19]. Their catalytic properties facilitate more efficient and environmentally friendly industrial processes. From petrochemical refining, catalytic fuel cracking processes, to biofuel production, zeolites contribute to minimizing waste, reducing energy consumption, and enhancing overall process sustainability. This not only aligns with the growing demand for eco-friendly practices but also fosters innovation in industries seeking to balance economic growth with environmental stewardship. These applications improve energy efficiency, reduce environmental impact, and contribute to cleaner air and a healthier environment, making them indispensable to sustainability initiatives. In the pursuit of renewable energy, zeolites are emerging as promising candidates for technologies such as energy storage and carbon capture [20]. These applications have the potential to significantly contribute to the transition to cleaner and more sustainable energy sources [1], thus reducing the world's reliance on fossil fuels. Furthermore, zeolites can be regenerated and reused, aligning with the principles of a circular economy where resources are conserved, waste is minimized, and sustainability is prioritized. Likewise, their ability to be effectively reintegrated into various processes extends their utility and environmental benefits as the world seeks innovative and sustainable solutions to complex problems.

III. Zeolites for Agriculture

Zeolites have emerged as an intriguing component in the quest for sustainable agriculture. Their properties, like high CEC [21], water retention capabilities [13], and soil-enhancing qualities, make them a versatile and eco-friendly tool in modern farming practices. Zeolites have the potential to revolutionize agriculture by significantly improving nutrient management, enhancing water conservation, soil amendments, treatment of animal waste products, as animal feed additive and mitigating soil salinity issues. They offer the promise of higher crop yields, reduced reliance on synthetic chemicals, and more efficient water use, all of which are vital components of sustainable agriculture, which

align perfectly with the broader goals of environmental issues and food security in the 21st century. In this context, this discussion delves deeper into the multifaceted contributions of zeolites to sustainable agriculture and their potential to transform the way we approach food production. The following parts will discuss their applications in improving soil quality, promoting responsible land management, while highlighting the significance of zeolites as a catalyst for a more sustainable and resilient agricultural future.

A. Zeolites as Effective Soil Amendments

Zeolite amendments may have a bigger impact on coarse-textured soils than on finer soils [21]. They are often noted for adsorbing and dispensing fertilizer at a slow controlled rate, also known as slow-release fertilizers [13]. Plant essentials like nitrogen and potassium are stored and released on demand by the negatively charged zeolite structure [17]. As a result, this application in agricultural activities can enhance both Water Use Efficiency (WUE) and Nutrient Use Efficiency, by lowering the risk of surface and groundwater pollution. Moreover, because of their microporous characteristics and capillary action, zeolites facilitate water infiltration and retention in the soil. Moreover, as natural wetting agents, zeolites can improve water retention in sandy soils and expand porosity in clay soils, allowing nutrients to be retained and yields to be increased. At the same time, they can be good carriers of nutrients/fertilizers as well as additional chemical and physical benefits, such as their use as artificial soil [15].

Zeolites serve as valuable soil amendments, enhancing soil structure and fertility through their unique properties. Mentioned below is how zeolites aid to facilitate nutrient availability and water management in the soil, contributing to overall agricultural productivity and sustainable land use practices.

1. CEC: Zeolites have a high CEC, which means they can hold and exchange a significant quantity of cations such as Ca^{2+}, Mg^{2+}, and K^{+}. When incorporated into the soil, zeolites increase the soil's CEC, effectively enhancing its ability to retain and supply essential nutrients to plants.

2. Nutrient Retention: Zeolites can adsorb and store essential nutrients, preventing them from leaching out of the soil, especially in sandy or coarse-textured soils. This ensures that plants have a consistent supply of vital minerals, ultimately leading to healthier growth and improved crop yields. The most used zeolite in such instances is Clinoptilolite.

3. Improved Water Retention and Drainage: Zeolites also help with moisture regulation in the soil. Their porosity can absorb and retain excess water in the soil, releasing it gradually to plants as needed. This is particularly useful in arid regions or soils prone to drought. Moreover, zeolites improve soil aeration and prevent compaction, allowing for better water drainage, which is vital for root health.

4. pH Buffering: Zeolites, mostly synthetic, can act as pH buffers, helping to stabilize soil pH levels. This is important because many plants have specific pH requirements for optimal growth. Zeolites can resist changes in soil pH and maintain a more stable environment for plant roots.

5. Improved Root Development: Zeolite amendments positively affect soil physical properties, including structure and aeration. This, in turn, encourages robust root development. As plants establish stronger and deeper root systems, they gain increased access to essential nutrients and water in the soil. Consequently, they become more resilient and better equipped to withstand environmental stresses and fluctuations, ultimately leading to healthier and more productive crops.

6. Reduced Fertilizer Requirements: By increasing nutrient availability and retention in the soil, zeolites can reduce the need for synthetic fertilizers. This not only saves costs but also minimizes the risk of nutrient runoff and pollution.

7. Disease Suppression: Zeolites can help suppress certain soil-borne diseases by inhibiting the growth of pathogenic microorganisms at the root of the plant. Zeolites create an unfavorable environment for pathogenic microorganisms by reducing moisture and providing an alkaline pH, thereby inhibiting their growth and helping to control soil-borne diseases in the root zone.

8. Environmental Benefits: The use of zeolites as soil amendments promotes sustainable and environmentally friendly agriculture by reducing the need for excessive chemical inputs, preventing nutrient runoff, and minimizing soil erosion.

When using zeolites as soil amendments, it's important to consider the specific type of zeolite and its compatibility with the soil and plants in question. Zeolite application rates, methods, and timing should be based on the specific needs of the crop and the characteristics of the soil. Overall, zeolites are valuable tools for enhancing soil quality, increasing agricultural productivity, and supporting sustainable farming practices.

B. Zeolites for Water and Nutrient Retention in Soil

Zeolites tend to create an impact on the physical properties of soil. The most notable effects are the reduction in soil bulk density and an increase in soil porosity. These factors, along with a large internal pore volume within its structure, can significantly increase their water holding capacity [14]. Additionally, they facilitate the creation of novel pathways for water flow, potentially increasing both the infiltration rate and the saturated hydraulic conductivity [13]. The infiltration rate pertains to the speed at which water enters the soil surface and is influenced by variations in the vertical hydraulic gradient across different spatial locations and time [19]. Hydraulic conductivity, another soil property, reflects the ease with which water moves within the soil and holds significance in the design of irrigation and drainage systems. Saturated hydraulic conductivity [15], represents the rate at which water can flow through the soil when it is fully saturated [21]. This is a crucial parameter used to model the movement of water and solutes within soil. This parameter has a substantial impact on deep water percolation, making it a key factor in optimizing water usage in agriculture. The control of solute movement in the soil is closely linked to hydraulic conductivity. Enhancing the hydraulic properties of soils can lead to more efficient water use, resulting in increased WUE and higher crop yields. Achieving this improvement in soil physical properties can be facilitated through the application of zeolitic soil amendments. Zeolites can influence hydraulic conductivity

owing to the channels within their structure, but it's important to note that the effect of zeolites varies depending on the soil texture. In heavy-textured soils, zeolites can increase hydraulic conductivity, while in light-textured soils, they may reduce it.

As urbanization continues to surge and concerns over water pollution, shortages, and the ever-increasing demand for food due to population growth intensify, there is a pressing requirement for dependable solutions in water irrigation and fertilization. The retention of both nutrients and water within agricultural soils plays a pivotal role in enhancing crop yields while concurrently serving as an effective preventive measure against waterway contamination and leaching, as illustrated in Figure 2.

Agricultural industries are known to be the main consumer of freshwater, as more than two-thirds of renewable water resources are utilized for agricultural purposes. In areas where renewable water resources are insufficient [20], water remains a vital component for development. Zeolites are also being examined as water regulators [19], as they can absorb up to 55% of their weight in water and release it gradually in line with the specific water requirements of plants. This characteristic is instrumental in averting root rot and managing mild drought cycles. Most surface-modified synthetic zeolites are capable of holding various nutrients such as phosphate (PO_4^{3-}), ammonium (NH_4^{+}), sulfate (SO_4^{2-}), nitrate (NO_3^{-}) and K^+, in their pores [22, 21]. It is possible to create such synthetic multifunctional adsorbents capable of capturing these anions and non-polar organic substances by modifying and altering their surface chemistry through the introduction of cationic surfactants [23] since most naturally occurring zeolites exhibit limited affinity for anionic fertilizers like NO_3^{-}, PO_4^{3-}, and SO_4^{2-}. The impact of zeolite applications on the physical and chemical properties of soil is contingent on various experimental factors, including the zeolite type, application rates, application methods, soil texture and structure, zeolite particle size and density, as well as the salinity of the water involved [24].

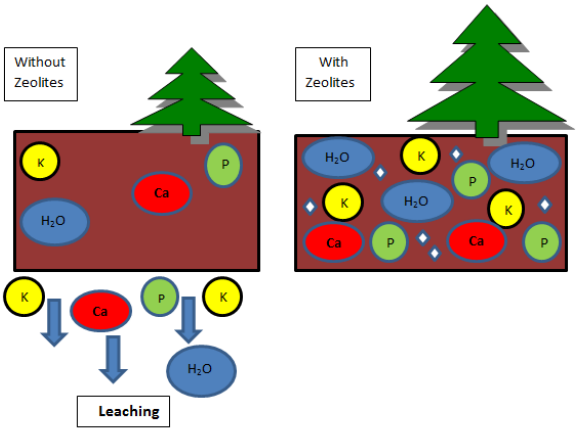

Fig. 2. Difference of water and nutrient retention in soil with the absence and presence of zeolites.

C. Zeolites for Weed and Pest Treatments

In the application of insecticides, herbicides, and pesticides, the ambient/environmental circumstances, commodity species of insects or plants, and the surrounding dust structure are major factors that influence the performance of zeolites and other inert minerals in insecticide and herbicide applications. Factors such as temperature, relative humidity, treatment method, characteristics of the insect species (developmental stage, size, softness of wax layers, hairiness, susceptibility, and physical mobility), and plant species are also used to evaluate the zeolite's potential. In addition, zeolitic properties such as its molecular structure, SiO_x content, particle shape and size, Si/Al ratios, adsorption ability, and geographical origin, have a direct impact on insecticidal potential. The use of adsorbents, silica gel, and alumina silicate crystals of zeolites has been shown to be effective for physical pest control as well as pesticide transporters, in addition to stored product pest management [15].

Zeolites, with their multifaceted applications in weed and pest management, have carved out a crucial role in modern agriculture and horticulture. Their versatility is evident in their dual function: first, they serve as efficient carriers for herbicides and pesticides, ensuring the gradual and controlled release of these chemicals. This controlled release [14] not only enhances the efficacy of agrochemicals but also lessens their environmental impact, mitigating concerns about chemical runoff and contamination. By prolonging the presence of these chemicals in the environment, zeolites enable precise targeting of pests and weeds, reducing the quantities needed and making pest control more sustainable. What further distinguishes zeolites is their innate ability to act as natural desiccants for insects and pests. By absorbing moisture from the exoskeletons of these organisms, zeolites induce desiccation, offering a non-toxic yet highly effective method of pest control [14]. This becomes particularly valuable in reducing reliance on chemical pesticides and the associated environmental risks. When integrated into the soil, zeolites bring an added dimension to weed and pest management. They enhance the physical properties of the soil, boosting its CEC and nutrient-holding capabilities. This not only fosters soil health but indirectly supports the robust growth of desirable plants, making them more competitive against unwanted intruders. The collective result is a more resilient and diverse ecosystem within the cultivated area.

Moreover, zeolites contribute significantly to moisture regulation [25] in the soil. By maintaining consistent and well-balanced moisture levels, they create less hospitable conditions for certain pests and weeds that tend to thrive in excessively wet or dry environments. This acts as a natural deterrent, minimizing the need for excessive chemical treatments. Furthermore, zeolites enhance fertilizer efficiency by reducing nutrient leaching. Nutrients remain accessible in the root zone of plants, allowing them to receive the right nutrients at the right time. This overall improvement in plant health aids in their competitiveness against weeds, reinforcing the sustainable aspect of zeolite-based weed and pest control. Zeolites, when thoughtfully employed, represent a greener and more eco-conscious approach to weed and pest control in agriculture and horticulture. By reducing the reliance on chemical pesticides, promoting soil health, and fostering plant vigor, zeolites not only enhance crop productivity but also contribute to a more sustainable and environmentally friendly agricultural ecosystem. Integrated pest management strategies that incorporate zeolites offer a well-rounded and

responsible approach to weed and pest control in today's farming and gardening practices.

D. Incorporation of Zeolites in Animal Husbandry and Feed Control.

Zeolites in animal husbandry [14] are instrumental in addressing a range of challenges, from controlling ammonia and managing odors to improving water quality and reducing stress in animals. One crucial advantage is their ability to control ammonia levels in confined animal facilities. Ammonia is a common byproduct of animal waste and can lead to respiratory problems and discomfort for animals. Zeolites adsorb and trap ammonia, effectively reducing its concentration in the air, which is essential for maintaining good air quality within animal housing. This, in turn, contributes to healthier and more comfortable living conditions for the animals, as lower ammonia levels reduce stress and the risk of respiratory issues. Zeolites also play a pivotal role in manure management, particularly in addressing the challenge of controlling odors associated with animal waste. When incorporated into manure or used as a bedding material, zeolites absorb and trap volatile organic compounds and gases responsible for foul odors [13, 14]. By controlling ammonia levels, improving air quality, and reducing the presence of unpleasant odors, zeolites create a more comfortable and less stressful living environment for the animals. Reduced stress can lead to positive outcomes in terms of animal health, behavior, and overall performance. In addition to addressing ammonia and odor issues, zeolites are valuable in improving water quality, especially in livestock operations that rely on water systems. Zeolites are used as a filtration medium for water. This ensures that they have access to clean and uncontaminated water. Better water quality is essential for the overall health and well-being of aquatic animals and livestock [13, 15].

Zeolites are a versatile and safe addition to animal feed, and their harmlessness is underpinned by several critical factors. One of the key attributes that ensures their safety is their chemical inertness. Zeolites are exceptionally stable [1] compounds that do not undergo chemical reactions within the animal's digestive system. This inertness means that when animals consume feed containing zeolites, these minerals pass through the digestive tract without being absorbed, digested, or altered in any way. As a result, they do not introduce any harmful byproducts or compounds into the animal's body. Another purpose that is served through the inclusion of zeolites, is the reduction of manure odors as toxins are adsorbed within the digestive tract of the animal by primarily binding to specific molecules, like mycotoxins [14], without interfering with the absorption of essential nutrients. Mycotoxins are toxic compounds produced by molds that can contaminate animal feed. When animals consume mycotoxin-contaminated feed, it can lead to various health issues, including reduced growth, immune system suppression, and digestive problems. Zeolites effectively adsorb mycotoxins, preventing these harmful compounds from being absorbed by the animal's digestive system. This helps protect the animals from mycotoxin-related health problems. They constitute only a small portion of the animal's diet, serving a specific purpose without significantly altering the overall feed composition. Regulatory approval and strict guidelines ensure that zeolites meet safety and efficacy standards for animal nutrition. Furthermore, zeolites can serve as carriers [1] for essential minerals and nutrients in animal feed. Their controlled release of these nutrients in the digestive tract enhances nutrient bioavailability, ultimately promoting better animal health and growth.

IV. Zeolites in Environmental Protection and Water Decontamination

In general, zeolites contribute to a cleaner, safer environment [11] in a variety of ways, and practically every application has been motivated by environmental concerns or plays a substantial part in the reduction of toxic waste. Zeolites can be used to safeguard the environment by purifying the air, soil, and water, as well as decontaminating the environment from radioactivity. However, they are integral to water purification due to their exceptional adsorption and ion-exchange capabilities. With their porosity and substantial surface area, zeolites effectively remove a wide range of impurities from water. They are employed in various water treatment processes [24], acting as filters or bed materials to trap contaminants. In addition to their adsorption properties, zeolites can exchange their cations with other cations present in the water, making them valuable for softening hard water [16] and removing undesirable ions. These minerals are employed in diverse applications, from softening [12] household water to purifying industrial wastewater, stabilizing pH, and catalyzing reactions for pollutant breakdown. The concentration of dissolved oxygen, non-ionized ammoniacal nitrogen, nitrites, nitrates, CO_2, water pH, and other characteristics determine the water quality. Zeolites are an essential component of both large-scale water treatment plants and smaller systems, offering efficient and environmentally friendly water purification solutions while addressing the aforementioned characteristics in water.

A. Sustainable Aquaculture Development with the Help of Zeolites

Zeolites play a pivotal role in aquaculture enhancement, serving as tools for improving water quality and fostering a healthier environment for aquatic organisms. These aid to effectively mitigate common challenges in aquaculture. By harnessing the unique attributes of zeolites, aquaculturists can create a more stable and conducive aquatic habitat, ultimately enhancing the growth and well-being of their fish and other aquatic species. They are widely utilized in the aquaculture business in several Southeast Asian and Latin American countries to improve water and feed quality [25], lessen aquaculture's negative environmental consequences, and improve the quality of grown seafood [25]. Zeolite has the ability to reduce or eliminate the content of nitrogen based compounds, heavy metals [16, 12], and organic materials [12] in fish ponds, as well as the ability to increase the content of oxygen, adjust pH, and minimize odors emitted from fish excretion, and the ability to decrease the content of suspended organic matter and Total Dissolved Solids (TDS) [25] in fish ponds, all of which have an impact on water quality. TDS is used to describe the inorganic salts and small amounts of organic matter present in solution in water, which might cause turbidity in water bodies. When

zeolite is mixed in fish feed, water turbidity is seen to be diminished [25].

Here is how they can be typically used in aquaculture farms for water purification in short:

1. Ammonia Removal: Ammonia is a common pollutant in aquaculture, primarily originating from fish excretion and uneaten feed. High ammonia levels can be toxic to aquatic organisms. Zeolites can adsorb and remove ammonia from the water due to their ion-exchange capacity. This helps maintain ammonia levels within acceptable limits.

2. Heavy Metal Removal: Zeolites can also adsorb heavy metals, such as copper, lead, and zinc, from the water. These metals can be harmful to aquatic life, and zeolites can help reduce their concentrations in the aquaculture system.

3. Nutrient Removal: Phosphates and nitrates are nutrients that can promote the growth of algae and other unwanted microorganisms in aquaculture systems. Zeolites can adsorb these nutrients, helping to maintain water quality and prevent eutrophication.

4. Water Clarity: Zeolites can help clarify water by adsorbing suspended particles and colloids. This can improve water clarity and create a more suitable environment for fish and other aquatic organisms.

5. Ion Exchange: Zeolites can be used to exchange undesirable ions in the water for desirable ones. For example, they can remove sodium ions and replace them with calcium and magnesium ions, which are essential for the health of aquatic organisms.

6. pH Stabilization: Zeolites can help stabilize the pH of water by buffering against sudden fluctuations. This is important because many aquatic species are sensitive to changes in pH levels. Zeolites act as ion-exchange materials, adsorbing excess ions, and stabilizing the water's pH level within a more neutral range. When acidic or alkaline ions are present in water, zeolites can exchange them with hydrogen or hydroxyl ions present within the framework, which helps buffer and maintain the pH at a desired level.

7. Bacterial Biofilms: Zeolites can provide a surface for beneficial bacteria to form biofilms. These bacteria can help break down organic matter and convert ammonia into less harmful forms, such as nitrate.

When using zeolites in aquaculture, it's essential to consider the specific requirements of the aquatic species being raised, the water quality parameters, and the type of zeolite used. Zeolites are typically placed in filters, columns, or reactors within the water circulation system. Periodic regeneration or replacement of zeolites may be necessary to maintain their effectiveness. Additionally, careful monitoring of water parameters and regular maintenance of the zeolite systems are crucial to ensure their continued performance in water purification.

B. Application of Macrophytes with Natural Zeolites for Water Treatment

Nitrogenous compounds are a significant concern in aquacultural systems due to their detrimental impact on various physiological factors in fish species, such as growth rate, oxygen consumption, and disease resistance. Aquatic plants, or macrophytes, play multiple roles in aquaculture, serving as biofilters, providing fish feed, reducing pollutants, and clarifying water. These plants facilitate nutrient transformations through physical, chemical, and microbial processes, while also utilizing nutrients for their own growth.

Recirculation aquaculture systems (RAS) [26] offer a novel approach to fish farming with several advantages over traditional methods. These systems allow for maximum production while minimizing water and land requirements and providing comprehensive control over environmental conditions during cultivation. However, the high costs associated with RAS wastewater treatment have prompted aquaculture scientists to explore more cost-effective filtration methods for these systems. In RAS, the incorporation of zeolites and macrophytic [27] plants as part of the filter for water treatment has significantly helped to decrease the presence of nitrogen and phosphorus compounds. The presence of zeolites and macrophytes in the experimental version improved water quality, which had a positive impact on fish development and feed consumption.

Combining the use of macrophytes and zeolites in aquaculture systems offers a range of significant advantages. First and foremost, this integrated approach results in efficient nitrogenous compound removal. Macrophytes absorb nutrients like nitrogen and phosphorus for their growth. Meanwhile, zeolites specialize in capturing excess ammonia. This dual action contributes to maintaining optimal nutrient levels in the water, ensuring a healthier aquatic environment for fish. By preventing nutrient imbalances and reducing the risk of harmful algal blooms, the combination of these natural and engineered systems creates a more stable and favorable environment for aquaculture. A second benefit is the improvement in water clarity and quality. Macrophytes play a vital role in this aspect by reducing suspended solids and fostering the growth of beneficial microorganisms. These microorganisms help break down organic matter, further contributing to water clarity and quality. Zeolites come into play by efficiently removing ammonia, a critical factor in maintaining water clarity and enhancing overall aquatic conditions. Clear water is not only aesthetically pleasing but also beneficial for fish health, as it allows for better observation and monitoring of the aquaculture environment.

One of the most significant advantages of this combination is the positive impact on fish health. Reduced toxic ammonia levels and improved water quality, achieved through the collaboration of macrophytes and zeolites, directly benefit the well-being and growth rates of the fish. Toxic ammonia is a known stressor for fish and can lead to various health issues. With its effective removal, the risk to fish health is minimized, leading to more robust and thriving populations. Additionally, the integrated use of macrophytes and zeolites can help reduce the environmental impact of aquaculture. Nutrient pollution in surrounding water bodies is a common concern in aquaculture, but the combination of these natural and engineered systems acts as an effective buffer. By keeping nutrient levels in check, it minimizes the

risk of pollution and contributes to a more sustainable and eco-friendly aquaculture operation.

However, it's crucial to recognize that the specific application and effectiveness of macrophytes and zeolites can vary based on the aquaculture setup, water conditions, and the species of fish being cultivated. Each aquaculture operation is unique, and therefore, careful consideration and ongoing monitoring are essential to tailor the use of macrophytes and zeolites for optimal results in each specific context.

V. Conclusion

In conclusion, the versatile applications of zeolites in sustainable agriculture and aquaculture underscore their significance in promoting environmentally responsible and efficient practices. Zeolites enhance soil fertility, improve nutrient and water retention, and contribute to healthier plant and aquatic life, reducing the reliance on synthetic chemicals and minimizing environmental impacts. Their role in water purification, from ammonia removal in aquaculture to pollutant adsorption in agriculture and animal husbandry, fosters cleaner ecosystems. Zeolites are crucial in reducing waste, conserving resources, and promoting soil and water quality. In an era of increasing environmental concerns and the imperative for sustainable practices, zeolites stand as valuable allies, contributing to the conservation of our natural resources and the advancement of ecologically sound agriculture and aquaculture.

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2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

Determination of the Climate Change Adaptability of Paddy-growing Farmers in Ampara District, Sri Lanka: A Case Study

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***Abstract*—Climate change poses a substantial threat to global agricultural systems, impacting the livelihoods of millions of farmers. This study endeavors to evaluate the adaptability of paddy farmers in the Ampara district of Sri Lanka—a region susceptible to changing climate patterns—in response to the challenges posed by climate change. A survey, utilizing a questionnaire, was administered to 100 voluntary participants. 73% of respondents derived their primary income from paddy cultivation, and all respondents exhibited awareness of climate change. Interestingly, 17% of participants relied solely on rainwater, while 69% met their water needs through a combination of rainwater and reservoirs. A significant majority, 98%, observed fluctuations in seasonal rainfall compared to previous years. The respondents employed diverse adaptation strategies, including modifying planting schedules, altering crop varieties, and adjusting irrigation practices. Among the surveyed group, 21% resort to rainwater collection, and 8% employ sediment removal techniques to improve the storage capacity of their irrigation reservoirs. Additionally, only 28% of respondents have transitioned to short-shelf-life rice varieties. Notably, 34% have adjusted their rice planting schedules to ensure sufficient water availability. 59% of the respondents have substituted indigenous paddy varieties such as Samba, AT 362, and BT 300 that can withstand climate change such as heavy floods and prolonged drought. Policymakers and stakeholders have the opportunity to devise focused initiatives aimed at enhancing the resilience of farmers confronting the challenges posed by climate change.**

Keywords—Rice cultivation, climate change adaptation, awareness, challenges

I. INTRODUCTION

Developing countries which are located in the tropical region are more susceptible to climate change-induced rising temperatures, and frequent floods [1]. The agricultural sector is considered one of the most vulnerable sectors to climate change [1, 2]. The change in the climatic parameters can impact significantly on irrigated agriculture [3]. The developing world is more vulnerable than the developed world because of its greater reliance on the agriculture sector for subsistence, lack of technological advancement, and absence of policies to adapt to climate change on agricultural production [1]. Climate change reduces agricultural productivity and increases the vulnerability of small and medium-sized respondents, whose primary sources of income are agriculture and related industries [1].

In Sri Lanka, 30% of paddy farming is dependent on rainfall, and 70% is dependent on irrigation [2]. Paddy fields that rely on large irrigation projects are less susceptible to short-term droughts but more susceptible to severe ones [2].

Low rainfall during the Maha season caused significant crop loss both during the season and the Yala season that followed [2]. The effects of climate change will include pollen desiccation, decreased production, an increase in pest and disease outbreaks, soil degradation, and decreased yield [2]. Rising temperatures can increase the rate of evapotranspiration and lower the water level in tanks and rivers [2, 3]. High levels of transpiration and evaporation can reduce soil moisture, stream flow, and groundwater recharge [3]. This can reduce the amount of water available for farming and increase the requirement for irrigation [3]. Soil salinization is a potential issue that arises from higher evaporation and decreased rainfall, which leads to a greater build-up of salt in the soil [3].

Furthermore, [4] found that paddy grown in rainfed lowlands is more vulnerable to weed competition than that in irrigated lowlands, suggesting that the availability of water has a significant role in determining the degree of weed interference [5]. Besides, the climatic zone will also affect the competitive pressure that weeds place on crops in the moisture-stressed dry zone; weed pressure is stronger than in the wet zone [5]. And, weed competition in Sri Lanka reduces paddy yield by around 20 - 40% or even 80 - 90% [5]. Thus, paddy cultivation in the dry zone is more vulnerable to climate change due to prolonged droughts and deficiency of rainfall [3]. So, it is crucial to comprehend and address the adaptive capability of rice respondents in the dry zone to guarantee the long-term sustainability and food security of Sri Lankan rice production. Researchers and policymakers can create tailored interventions to support rice respondents in the dry zone in their efforts to adapt by having a thorough grasp of the unique obstacles they encounter. The scope of this study is limited to Ampara district which is one of the major rice production regions in Sri Lanka. The Ampara district is severely affected by prolonged droughts and heavy rainfall due to climate variability. Thus, the determination of the adaptability of respondents in the Ampara district is crucial to identify the constraints, gaps, and opportunities to continue their production without compromising any loss.

II. Materials and Methods

A. Study Area

Ampara district in the Eastern Province was selected as the study area for this study. Lahugala (Waralanda, Dawalgoda, Perani Lahugala), Panama (Panama north, Panama South, Panama Central, Panama Western), Uhana (Gonagala, Senagama, Verenkatagoda Mayadunna, Kothmale (K.C. Colony), Bandaraduwa, Gonagolla) Paragahakele), Dehiattakandiya (Lihiniyagala, Damunnuwara) Divisional Secretariat divisions were selected for this study.

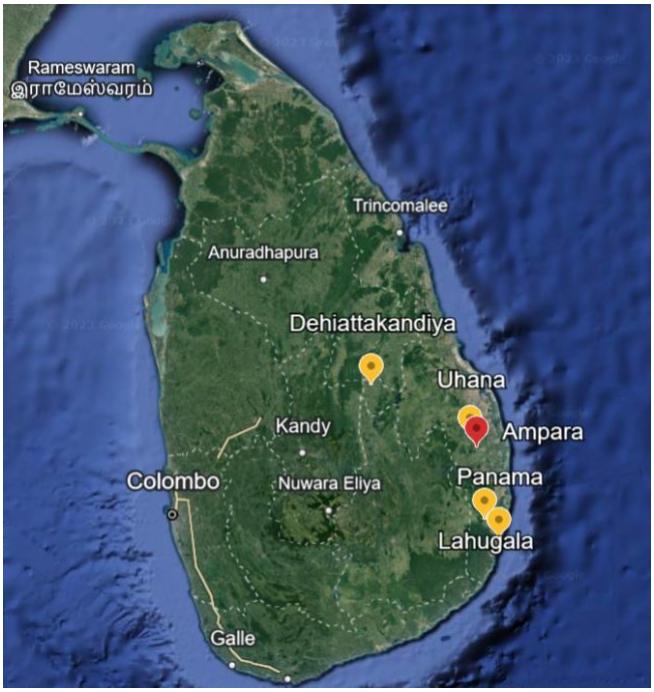

Fig. 1: Areal view of study area (google earth)

B. Questionnaire Survey

A questionnaire-based study was conducted to collect data on rice production and other climate impacts. A population of 100 respondents was selected based on the random sampling method. The questionnaire survey was conducted physically in September 2023. The questionnaire consisted of 9 main sections with 67 questions, closed-ended questions, and open-ended questions. The nine sections included: Section 1- Demographic Information (Q1.1 - Q1.12), Section 2 - Climate Change Awareness (Q2.1 - Q2.2), Section 3 - Water supply (Q3.1 - Q3.12), Section 4 - Impact of rainfalls (Q4.1 - Q4.10), Section 5 - Impact of dry weather on rice crops (Q5.1 - Q5.8), Section 6- Pest and diseases (Q6.1-Q6.8), Section 7 - Crop loss and compensation (Q7.1 - Q7.4), Section 8 - Adaptation Practices (Q8.1 - Q8.9), and Section 9 - Access to Resources (Q9.1 - Q9.4).

Ethical consent was obtained from individuals before the research due to their participation in this study. Also, the individuals were informed at the beginning of the survey that their demographic details and responses to the questions would be collected only for the study. All the respondents participated in the survey as volunteers and before the survey, they were informed about the purpose of the study and its main results and participated in the survey based on their consent. The collected information was analyzed using Excel software and the respondents were tabulated as a percentage of the total number of respondents and analyzed as the final result.

III. Results and Discussion

A. Demographic Characteristics of the Respondents

Responses to the demographic characteristics of the respondents are tabulated as percentages from the total number of responses as given in Table 1. 73% of them are mainly engaged in paddy cultivation as their livelihood, 6% are engaged in chena cultivation and 3% are engaged in retail trade. During last *Yala* season, only 7% have successfully attained their anticipated crop yields. 91% of the respondents failed to attain the harvest as they expected due to inadequate fertilizer distribution, the quality of fertilizers, and irregular rainfall patterns. However, 2% of the respondents managed to achieve average yields. Respondents grow other crops such as peas, green beans, peas, melons, and kurakkan to enrich the soil, especially with nitrogen and phosphorus. Only 2% of respondents grow as intercrops in all intermediate seasons. 48% of the respondents cultivate intermediate crops in some intermediate seasons, and 50% of respondents never grow intercrops other than paddy.

B. Climate Change Awareness

All the farmers (100% of the respondents) were aware of climate change and its potential impacts on agriculture. 98% of respondents have observed changes in climate patterns in their regions over the past decade, while 2% have not observed any change with respect to their climate.

C. Water Supply

As shown in Fig. 2, the majority (69%) of respondents fulfill their water requirements through both rainwater and reservoirs. The channels from the main reservoirs provide water for the remaining 2% of the respondents. The respondents who depend on rainwater entirely lack proper methods such as irrigation tanks to store rainwater during the rainy season. So, these respondents only cultivate during the *Maha* season of the year. 23% of respondents get irrigation water from the main reservoir (Senanayake reservoir) (Figure 3), 38% of respondents from canals, and 39% of respondents from village tanks (Ulhitiyawa Lake, Maha Lake, Meeyangoda Lake, Namal Oya). And some other respondents' cross canals to collect water.

40% of respondents reported that flooding and bank breaches had impacted the irrigation reservoirs in their regions. To mitigate the flood-related damage to these reservoirs, respondents employed strategies such as constructing embankments and deploying sandbags near the areas with high water levels. On the other hand, for 60% of respondents, the irrigation reservoirs in their areas remained unaffected by floods.

Table 1: Demographic Characteristics of the Selected Population (As A Percentage of the Total Population of 100)

Demographic features		Percentage
Age	30-39 years	10%
	40-49 years	18%
	50-59 years	40%
	60-69 years	32%
	70-79 years	7%
	80-89 years	1%
Gender	Male	86%
	Female	14%
Experience of paddy cultivation	less than 10 years	6%
	10-20 years	8%
	20-30 years	18%
	30-40 years	30%
	40-50 years	26%
	50-60 years	12%
Extent of paddy cultivation	less than five acres	75%
	5-10 acres	15%
	10-15 acres	7%
	15-20 acres	3%

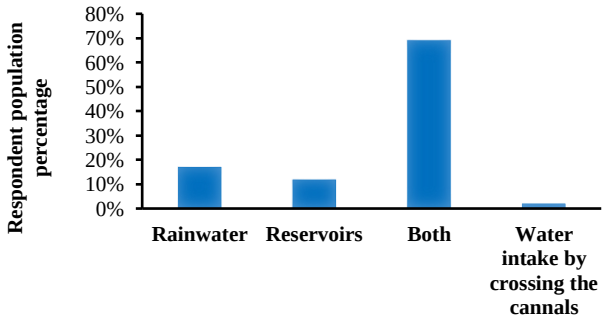

Fig. 2. Main source of water for paddy cultivation of the responded population

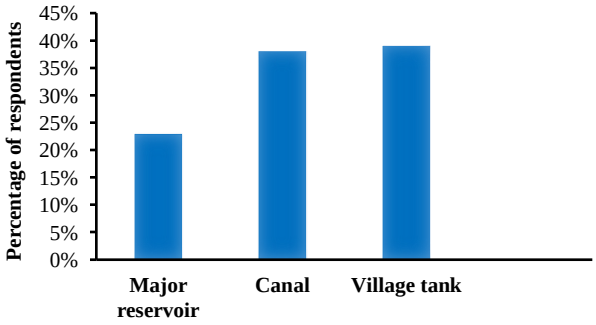

Fig. 3. Methods of irrigation water supply of the responded population

According to all the farmers, government organizations, specifically the Irrigation Department, have been diligently working on restoring the impaired reservoirs to their optimal operational state. 15% of these respondents have taken the initiative to refurbish their abandoned irrigation tanks, which include the Maha Lake, Yalpotha Lake, and Kithulana Lake. Additionally, 7% of respondents in their respective villages have implemented substantial mega irrigation projects, such as Heda oya, Wegama Lake, and Adal oya, to ensure a consistent water supply for paddy cultivation. However, the remaining 93% of villages do not have access to mega irrigation projects. In the surveyed agricultural regions, several respondents have proactively adopted water conservation practices for their paddy cultivation activities, particularly during the dry season. Notably, 21% of these respondents engage in rainwater collection, while 8% implement sediment removal techniques to enhance the storage capacity of their irrigation reservoirs. Regrettably, the majority of respondents, constituting 71%, have yet to employ any water conservation methods. Moreover, 43% of the respondents faced conflicts arising from water scarcity during extended drought periods, while 57% of them managed to avoid such conflicts. Encouragingly, for 81.8% of the respondents, engaging in discussions proved to be an effective means of resolving these water-related challenges. Furthermore, 18.20% of the respondents believe that conducting discussions and ensuring the equitable distribution of water between upper and lower paddies can serve as a viable solution to mitigate such conflicts.

D. Impacts of Rainfall

The monsoon rains play a pivotal role for rice farmers residing in the dry zone, as their livelihoods are intricately linked to irrigation reservoirs primarily replenished by rainfall. Additionally, some farmers directly rely on rain for their water supply. Furthermore, all farmers conduct essential tillage operations in their fields, predominantly contingent upon the presence of rainfall. Notably, 98% of these respondents have noticed variations in seasonal rainfall when compared to previous years, underscoring the changing climate patterns. In contrast, a mere 2% of the respondents have not observed such fluctuations. The majority of respondents, accounting for 66%, have noticed alterations in rainfall patterns during both the Maha and Yala seasons. Furthermore, 29% of the respondents have specifically observed shifts in the Maha season, while a mere 3% have reported changes in the Yala season. However, a small fraction of 2% of the respondents have not discerned any variations in monsoonal rainfall.

As reported by the majority of respondents, specifically 97%, the monsoon rains were delayed, arriving later than the expected schedule. In contrast, only 3% of respondents received the monsoonal rains at their usual time. In terms of crop losses, around 53% of respondents experienced losses ranging from 0-1000 kg. Within this group, 13.2% faced complete crop failure during certain seasons. Additionally, nearly 14% of respondents incurred losses between 2000 kg and 5000 kg, while 19% experienced losses ranging from 1000 kg to 2000 kg. A smaller fraction, 1%, had more substantial losses, falling within the range of 5000 kg to 10,000 kg. Furthermore, 6% of the remaining respondents reported both partial and total damage to their crops. Surprisingly, 7% of respondents held the belief that rainfall does not pose a threat to their crops.

The influence of rainfall on paddy cultivation can fluctuate depending on the specific stages of the paddy's life cycle. Approximately 55% of the respondents encountered substantial challenges from rainfall during the harvest period, while roughly 16% faced significant impacts during the ripening phase. A smaller percentage, approximately 2%, reported adverse effects during the vegetation stage. In addition, 17% of the respondents mentioned that their crops were damaged specifically during the ripening stage, and 1% indicated damage occurring solely during the harvesting period. A distinct group of 7% of the respondents suffered from damages during all three phases of the vegetation period, ripening period, and harvesting period.

Reduction in rainfall and increased unpredictability will disrupt the cropping calendar in addition to impacting crop output [6]. In Sri Lanka, later monsoon arrivals can result in shorter growing seasons [6]. Rainfall can have various detrimental effects on rice cultivation, including damage

caused by mites, crop loss during the ripening phase, reduced yields, stunted plant growth, rotting of plants in waterlogged paddy fields, insect infestations, formation of unproductive pods, yield reduction due to pollen washout, and inundation of crops due to flooding. Furthermore, heavy rains can result in damage to paddy fields through tree uprooting, dam breaches, crop destruction, soil erosion, and sediment deposition in fields. During the harvesting stage, excessive rainfall can impede proper harvesting and hinder the drying process for the harvested paddy.

E. Impact of Dry Weather on Paddy Cultivation

The duration of the dry season in the Ampara district varies depending on the area. In some areas, the dry season extends for a period of eight months, while in others, a severe drought can persist for two months. These extended dry periods, characterized by insufficient rainfall, have significant consequences for agriculture. Elevated nighttime mean temperatures have a pronounced effect on rice production, as demonstrated by various studies [6]. Research conducted at the International Rice Research Institute farm revealed a 10% decline in paddy yield for every 1°C increase in the minimum temperature during the growing season in the dry season [6].

Elevated temperatures pose a threat to lower-altitude regions worldwide, especially those already experiencing warm conditions [7]. In regions where climate change leads to temperatures surpassing optimal levels, there is an escalation in the release of CO_2, accompanied by a reduction in photosynthesis activities. This ultimately impacts plant physiology and yield [7]. Similarly, temperatures higher than the optimal range or warmer conditions foster increased insect pest growth, elevating the risk of reduced plant production [7]. Climate change further alters the patterns of rainfall, affecting the extent and distribution of evapotranspiration [7]. This disruption influences soil water content, drainage, runoff, and water uptake by plants [7]. Both flooding and drought, stemming from these climate shifts, adversely impact crucial plant growth stages such as flowering, pollination, and grain filling [7].

Elevated temperatures have a detrimental impact on cellular and developmental processes, resulting in decreased fertility of spikelets and reduced grain weight [7]. This adverse influence extends to the quality of the grains, manifesting as a higher percentage of chalkiness and lower amylose content during the grain filling and ripening phase in rice [7]. The persistent rise in temperature further shortens the plant growth cycle, adversely affecting rice yield [7]. During the dry season, respondents in the Ampara district collect water from sources such as Senanayake and regional tanks, as well as irrigation channels, which they then distribute using pipes. However, in areas lacking water resources, such as Panama and Lahugala, cultivation during the Yala season becomes unfeasible. Consequently, the agricultural productivity of the Ampara district during the dry season is hampered by the unavailability of a continuous water supply. This study has confirmed that both the reproductive and vegetative stages of rice are particularly susceptible to drought in this region during paddy cultivation. A significant majority of respondents, approximately 93%, have adapted to the practice of applying liquid fertilizers during the morning and evening. This method helps to mitigate fertilizer loss caused by intensified solar radiation. In contrast, 7% of respondents do not employ liquid fertilizers. Additionally, around 9% of respondents have opted for an organic fertilizer known as "Jivashakti fertilizer," which demonstrates resilience against evaporation-related losses

F. Pests and Diseases

In paddy cultivation during adverse weather conditions, various pests, including caterpillars (such as green hornworms), thrips, aphids, mites, worms (like earworms and cutworms), rice flies, grasshoppers, bugs, and butterflies, are commonly encountered. Fungal diseases tend to be more prevalent during dry seasons, as wind and temperature fluctuations influence their spread. Effective management of insects during warm weather can significantly reduce damage. To address these issues, a range of control measures, such as the use of insecticides, seeking guidance from agricultural experts, periodic cultivation, and the drainage of excess water from paddies, are typically employed in standard agricultural practices within these regions. However, in the Ampara district of the dry zone, elephants pose the primary threat to paddy respondents during unfavorable weather conditions. These majestic creatures inflict severe damage to paddy crops through both consumption and trampling. The individuals engaged in paddy cultivation often face various health issues, including rat fever, skin ailments, respiratory issues, kidney disease, gout, and damage caused by caterpillars. The increased incidence of rat fever is particularly associated with high levels of rainfall.

G. Crop Loss and Compensation

Out of the surveyed respondents, 31% have been recipients of government compensation to offset harvest losses, while the remaining 69% have not received such compensation. Regarding financial recovery, 33% of respondents rely on credit to cope with their losses, while the majority, constituting 67% of the respondents, do not depend on credit. In terms of livelihood adjustments due to climate change-induced crop losses, 8% of respondents have changed their primary source of income, whereas the overwhelming majority, accounting for 92% of the respondents, have retained their original source of income.

H. Adaptation Practices

[8] classified agricultural adaptation possibilities into four key categories: (1) government programs and insurance; (2) technical improvements; (3) farm production techniques; and (4) farm financial management. Government agencies make most of the decisions in categories 1 and 2, whereas producers make the majority of the decisions in categories 3

and 4. In this study, categories 3 and 4 were mainly focused. Only 28% of respondents shifted into short-shelf-life rice varieties such as H10, and Basmathi (75 days)], while the remaining 72% of the respondents have not adopted short-shelf-life rice. 34% of the respondents have changed their rice planting times to get enough water (Figure 4), and 66% of the respondents have not changed their rice planting times. 79% of the respondents were aware that local rice varieties such as H4, H5, H8, and BG11 can withstand climate change such as heavy floods and long droughts, and according to 21% of the respondents, the local rice varieties cannot withstand climate change. 59% of the respondents have substituted indigenous paddy varieties such as Samba, AT 362, and BT 300 that can withstand climate change such as heavy floods and prolonged drought, while 59% of the respondents have not substituted indigenous paddy varieties.1% of respondents have shifted to areas that are less vulnerable to the effects of climate change, while 99% of respondents have not 20% of the respondents have changed to crops that can withstand extreme climate conditions and 80% of the respondents have not changed to other crops. 15% of the respondents have changed their paddy cultivation to crop types such as peanuts, mung beans, cowpeas, and bananas that can withstand extreme climatic conditions, while 85% of the respondents have not changed their paddy cultivation to other crop types. Reduction in rainfall and increased unpredictability will disrupt the cropping calendar in addition to impacting crop output. In Sri Lanka, later monsoon arrivals can result in shorter growing seasons [6]. As shown in Figure 4, changing planting dates, using drought-resistant rice varieties, altering irrigation methods, crop rotation or diversification, and soil conservation practices have been identified as key adaption measures

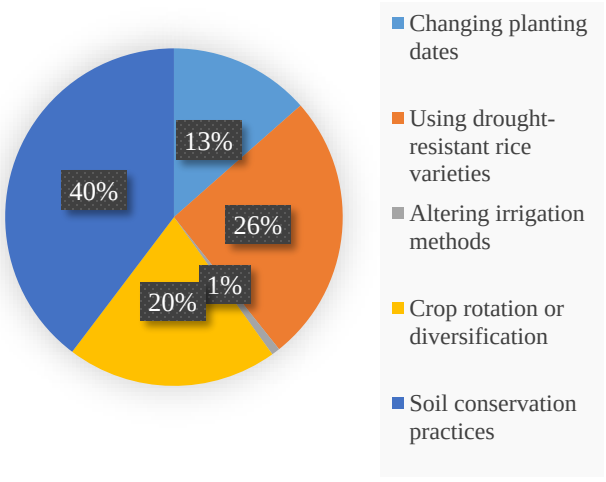

Fig. 4. Adaptation practices farmers have implemented or considered to address climate-related challenges

I. Access to Resources

A respondent's ability to successfully adapt and respond to the challenges of climate change is intricately tied to their knowledge, skills, past experiences, and various socio-economic factors [9]. A significant 90% of respondents have access to climate information and forecasts specific to their region. In contrast, 10% of respondents lack access to such vital climate information and forecasts, primarily due to lower technical literacy and financial constraints. Nonetheless, it's important to note that general weather forecasting doesn't always provide location-specific meteorological data, which can impede respondent's adaptation efforts in the face of ongoing extreme weather conditions. 7% of respondents have financial or resource constraints that hinder their ability to adopt climate-resilient practices, and 93% have no such financial or resource constraints. 26% of respondents have government programs or initiatives supporting climate-resilient paddy cultivation in their regions, and 74% of respondents do not have these government programs or initiatives. Regarding government programs or initiatives to support climate-resilient rice cultivation in this area, some selected individuals participate in the Yala and Maha seasons meetings, programs of respondents' associations, and programs conducted by the Department of Agriculture. 62% of respondents have participated in government-led training programs related to climate change adaptation in agriculture, while 38% of respondents have not.

I. Way Forward

To enhance respondent's resilience in the face of extreme climatic conditions, the adoption of climate-smart agricultural practices is crucial. Implementing temporary check dams constructed from sandbags or polybags can effectively store rainwater in reservoirs, bolstering water availability and groundwater replenishment. Furthermore, the introduction of direct-seeded rice cultivation is a viable option, as it helps to conserve water. Unlike transplanting paddy, which leads to water loss through runoff, percolation, and evaporation, direct seeding proves to be more efficient. Additionally, the utilization of micro-irrigation techniques, including surface drip irrigation and subsurface drip irrigation, offers the flexibility to apply water according to the specific needs of the crops. This approach minimizes water loss through percolation and surface runoff. Moreover, the implementation of the Alternative Wetting and Drying (AWD) method stands out as a promising strategy, as it significantly enhances water productivity compared to traditional flooded fields or submerged regimes. In addition, government funding should be allocated for the establishment of rainwater harvesting systems in areas lacking the necessary infrastructure. Initiatives like the installation of rainwater harvesting tanks, the construction of irrigation reservoirs, and the development of canals to redirect water from existing irrigation sources can empower respondents in this region to sustain agricultural activities even during prolonged dry spells.

It is imperative to arrange awareness programs at the grassroots level to help respondents recognize the significance of adapting to climate change. Additionally, effective weather forecasting plays a pivotal role in assisting paddy respondents in their adaptation efforts to mitigate the impacts of extreme climatic conditions. To improve respondent's access to weather and climate information and enable them to make informed decisions, it is essential to boost their digital literacy. Facilitating the sharing of weather information among fellow respondents can be especially beneficial for those facing financial constraints, allowing them to access timely weather updates. Furthermore, the government should allocate funding for the installation of additional meteorological stations in regions more prone to drought. This investment will ensure the availability of location-specific meteorological data, ultimately aiding respondents in managing extreme weather conditions effectively.

IV. CONCLUSION

This study underscores the pressing necessity to address the adaptability of paddy respondents in the dry zone to climate change. The profound impacts of shifting climatic conditions, coupled with financial limitations and a lack of awareness, pose substantial hurdles. Promoting climate-smart agricultural practices is of paramount importance in bolstering resilience within this vulnerable region. It is imperative to concentrate on furnishing financial assistance, enhancing awareness, and equipping respondents with the requisite knowledge and tools to secure a sustainable and flexible future for paddy farming in the dry zone.

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2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

Quad-band GSM/GPRS Enabled Low-Power Sensor Node Design For Outdoor IoT Applications

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***Abstract*—This paper introduces an energy-efficient and low-power sensor node tailored for outdoor Internet of Things (IoT) applications. The node establishes a direct connection with cellular base stations across GSM/GPRS quad-bands at 850 MHz, 900 MHz, 1800 MHz, and 1900 MHz. Comprising a central controller utilizing ATMega328, a communication module employing SIM800, and a DHT22 temperature and humidity sensor, the sensor node is equipped with a solar-powered charging system. Specifically designed for robust IoT outdoor applications, the implemented energy-saving mechanism relies on deep sleep scheduling, significantly reducing power consumption and extending the sensor node's uptime**

Keywords—IoT, GSM/GPRS, wireless sensor networks, industrial IoT

I. INTRODUCTION

Internet of Things (IoT) applications could consider as the most emerging area in electronics engineering. IoT applications exist in almost every field, such as smart agriculture, farming, intelligent transportations, intelligent buildings, etc. Further, many IoT applications exist both indoors and outdoors. The design architectures may vary on the IoT application deployed. For instance, indoor applications, sensor nodes could connect in a wireless LAN via a wireless router. And nodes connect with remote IoT cloud via broadband routers. It is impractical to use broadband routers in these designs in outdoor applications as the range between sensor nodes, and router may be far away. Such designs could use GSM/GPRS-based technologies where sensor nodes could directly connect with 3G/4G mobile base stations. SIM 800 supports four GSM bands 850/900/1800/1900MHz. This paper designed and deployed an IoT sensor node for outdoor IoT applications such as real-time environmental condition monitoring. In this design, the Atmega328 microcontroller is used as the central controller, and the SIM800 module is used to connect with the cellular network. To power up the node, 12V,500mAh battery has been used with a 50 watts photovoltaic charging system to ensure the continuous wakeup of the node. A novel wakeup scheduling mechanism has been proposed, deployed, and evaluated to save the node's power consumption.

One of the primary motivations behind our work is cost-effectiveness. While market ready IoT sensor nodes are readily available, their high cost renders them unaffordable for communities such as farmers seeking to employ environmental monitoring in their fields.

The rest of the paper has been organized as follows. Section II presents the recent works that exist on Atmega328 based systems and techniques used for power management. Section III discusses all the required steps of designing the sensor node, and section IV present the energy-saving mechanism used in the system. Section V presents the experimentation results and discussion and, finally, the conclusion.

II. RELATED WORKS

Related works are existing on designing low-power IoT systems using microcontrollers [1-5]. Many works, designed for indoor applications such as home automation systems, robotic systems. Moreover, systems designs are included with broadband wireless routers as applications are indoor. A limited number of related works exist on IoT designs on GSM [6]. Even these designs are limited to a prototype.

Generally, once deployed sensor nodes it is impossible to replace or recharge the batteries of the nodes. Therefore, applying an energy-saving mechanism to prolong the uptime. To save energy, several power-saving techniques have been used in the literature, such as duty cycling, transmitted data reduction, transceiver optimization, energy-provision schemes, overhead protocol reduction, voltage control, and current control [7-10]

This sensor node has been designed from scratch for the final product. This includes waterproof enclosed and a reliable power supply. The photovoltaic power panel support runs the sensor node even at night time also. Further, energy-saving techniques have been applied to save energy.

III. SYSTEM DESIGN

The system overview is as shown in Fig.1 Atmega328p microcontroller is used as the central controller. The DHT 22 is the sensor to monitor temperature and humidity. The DHT sensor is calibrated. The communication module is designed based on SIM 800 chip. The SIM800 is a complete Quad-band GSM/GPRS solution in an SMT module embedded in the customer applications. Featuring an industry-standard interface, the SIM800 delivers GSM/GPRS for bands 850 MHz,900 MHz,1800 MHz and 1900 MHz performance for voice, SMS, data, and low power consumption [11] with a tiny configuration of 24mm x 24mm x 3 mm, SIM800 can fit almost all the space requirements in IoT devices. The ThingSpeak cloud [12] is used as the IoT cloud. Where HTTP protocol was used to transmit data sensed by sensors to this cloud server. The Fig. 2 shows the power supply designed for the unit. Where LM2596 used with a buck—converter to separate 12V line for the main controller(ATmega328p) and

MIC23302 was used to have a sperate power connection of 4.8V to the communication node(SIM800). Fig.3, and 4 show the schematic diagrams for both the main controller circuit and communication module respectively. In communication module, there two separate LED indicators to indicate GPRS connectivity status and GSM connectivity status. The main controller also with additional GPIOs to connect additional sensors and actuators. Fig. 5-8 the final design view of the sensor node. The circuit was designed using Altium Designer and generated Gerber file used to manufacture the PCBs.

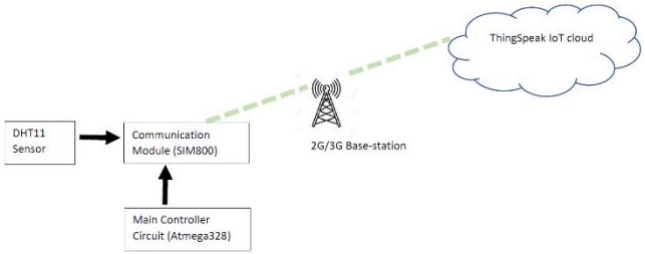

Fig.1: System overview

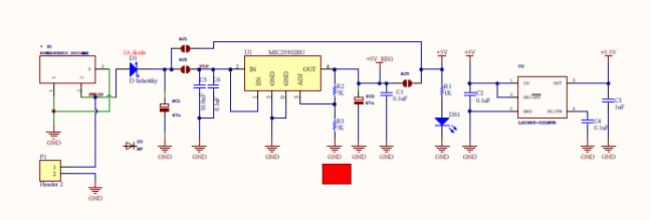

Fig.2: Power controller designed for the central controller

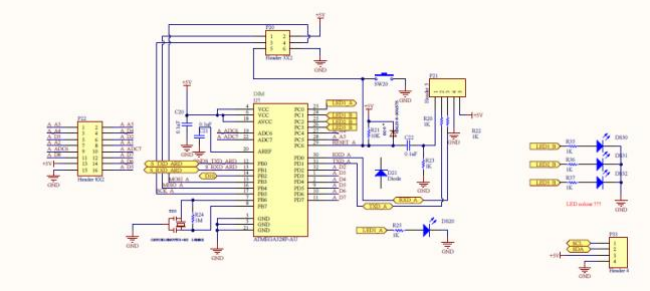

Fig.3: Main controller designed using ATMega328p

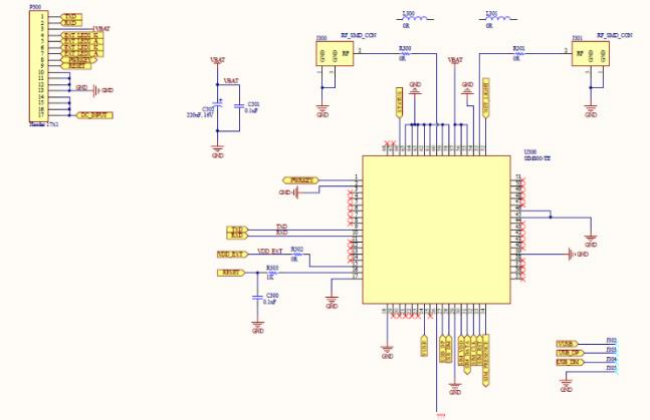

Fig.4: A schematic design for SIM800 based communication module

This project was funded by General Sir John Kotelawla Defence University, Sri Lanka, under the research grant scheme

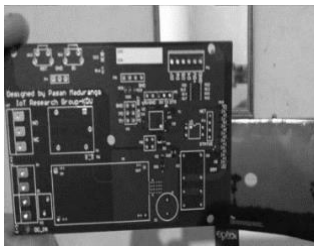

Fig. 5. PCBs

Fig.6. Assembled circuit

Fig.7. Sensor node inside the enclosed

Fig.8. Installation with 50W solar panel

IV. Real-Time Monitoring

The system can monitor the real-time temperature and humidity using any devices connected to the ThingSpeak cloud. Also, this cloud service is free, and it also allows to save the data with certain limitations. Fig. 3 shows the recorded temperate and humidity data for 24 hours. In IoT data analytics, it is essential to use data filtering techniques to remove the noises made by sensors. Thus Fig.9 shows filtered data, filtered using moving average filters.

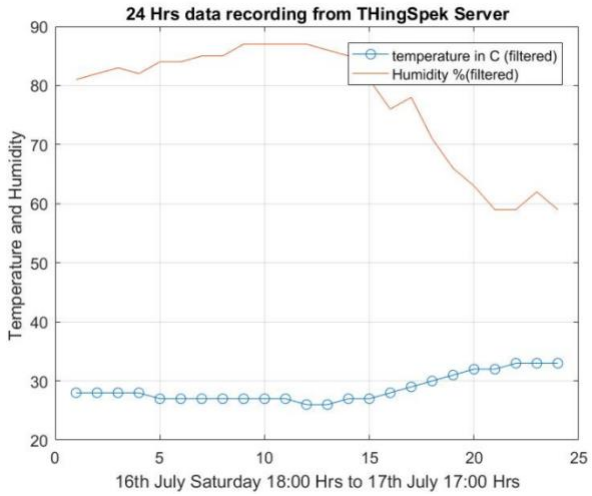

Fig. 9. Temperature and humidity data for 24 hrs

V. Energy Saving Techniques

Applying energy-saving techniques to a sensor node is crucial. In most practical applications, the battery is not replacing or recharging once the sensor node is deployed. Therefore, saving limited energy in the batteries is essential to prolonging the sensor wakeup. Generally, the radio module

consumes more power as it consumes more power for transmission [1, 13]. Therefore, our proposed sleep scheduling method is applied to the communication module. Usually, the SIM800 module consumes 453mA during the data transmissions and 1mA in deep sleep mode [7, 11]. Fig. 10 shows the proposed duty cycling for the SIM800 module in the communication module.

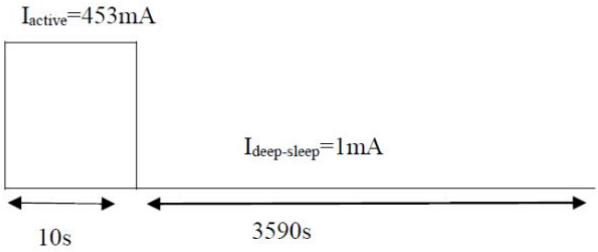

Fig.10: Duty cycle for communication module

Capacity of the used rechargeable battery is 1Ah,

$$Capacity, C = 500mAh$$
$$= 500mA * 3600s$$
$$= 1{,}800{,}000mA - secs$$

When the SIM800 module transmits data to the internet via Wi-Fi, let's assume that the active state current (Inactive) is measured as 453mA.

$$Iactive = 453mA$$

While the SIM800 module is in deep-sleep mode, let's assume that the deep-sleep current ($I_{deepsleep}$) measures as 1 mA.

$$Ideep - sleep = 1mA$$

1 cycle of current measurement contains T secs

$$T = t1 + t2 \quad (1)$$
$$T = 10\,secs + 3590\,secs = 3600secs$$

Hence, the average current consumed in 1 cycle is:

$$Iaverage = \int_0^{10} 453mA\,dt + \int_{10}^{3590} 1mA\,dt \quad (2)$$
$$Iaverage = 8110mA - sec$$

The average current in mA Iaverage(mA) is given by:

$$Iaverage(mA) = \frac{Iaverage(mA - sec)}{T} \quad (3)$$
$$= \frac{8110mA - sec}{3600sec}$$
$$= 2.2527mA$$

If L denotes the estimated life-span of the sensor node

$$L = \frac{C}{Iavarage} \quad (4)$$
$$L = \frac{500mA - hr}{2.2527mA}$$
$$L = 221.95\,hrs$$
$$L = 9\,days\ approximately$$

VI. Experimentations and Discussion

We conducted outdoor testing of our system over several consecutive days, divided into two phases. Initially, the system was deployed without energy-saving techniques to observe node uptime. Subsequently, we applied an energy-saving mechanism and monitored node uptime. The results indicated that the sensor node could remain active for two days after fully charging the batteries without implementing energy-saving techniques. In contrast, when the experiment was repeated with a deep-sleep-enabled schedule, the sensor node remained operational for approximately five days. Notably, during both experiments, the solar panel was not connected.

It was observed that the application of the energy-saving mechanism resulted in a deviation between the theoretically calculated and experimentally observed values for the sensor node's wakeup time. This discrepancy arose from solely considering the current theoretical values provided in the SIM800 datasheet. However, in the entire communication circuit, the current draws and power consumption could be higher, contributing to the observed differences.

VII. Conclusions

In this paper, we present a comprehensive design for a GSM/GPRS-based IoT sensor node tailored for outdoor applications. Notably, this system eliminates the need for additional routers as an access point to connect with the IoT cloud. The communication model, powered by GSM/GPRS, enables direct data transmission to the nearest mobile base station via GPRS. The simplicity of this design renders it versatile for various outdoor IoT applications, including environmental condition monitoring, animal tracking, military applications, and more. Given its support for 2.5G/GPRS and incorporation of an additional solar power backup, the system proves particularly useful in rural areas with only 2.5G coverage. An innovative energy-saving mechanism, employing duty cycles, has been introduced in the sensor node, significantly extending its wakeup time.

Acknowledgment

This work is supported by research grant schemes of General Sir John Kotelawala Defence University under grant number KDU/RG/2020/FOC/001.

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2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

Study on the Application of Continuous Variable Transmission [CVT] Technology to Manual Transmission Three-Wheeler

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***Abstract*—Automobile engineers are concerned about the parameters which are performance, efficiencies, safety, comfortability, budget, and environmental friendliness while designing a new vehicle. Currently, vehicles with automatic transmissions are getting more prominence over ones with manual transmissions in the case of newly designed vehicles. In this research aim is to convert a manual transmission vehicle to an automatic transmission. Therefore, a 4-stroke 205cc three-wheeler with a manual transmission is converted into an automatic transmission system by using rubber V-belt CVT technology. The significant benefits and drawbacks were analyzed to select Belt CVT technology for this approach. The power transmission starts from the flywheel to the Primary pulley of the CVT via a chain drive mechanism. while a secondary pulley of the CVT is directly connected to the differential gear setup. Both the primary pulley and secondary pulley are connected by a Rubber V-belt for power transmission. The physically developed model of the research has achieved a maximum speed of 24kmph while experiencing troubles under off-road conditions with high fuel consumption. The reason for such low speeds was addressed as the impact of the weight of the rollers in the pullies. The reverse drive remained unchanged. Simultaneously it has resulted in comfortable driving, less fatigue, ease of driving, and suitability for disabled individuals. A future direction has been highlighted with the application of center springs of the secondary pulley and weight reduction of the roller weights.**

Keywords—CVT Technology, Automatic Transmission, Three-wheeler, Chain drive mechanism, Rubber V-belt

I. INTRODUCTION

In Asian and African countries millions of three-wheelers are used as taxi services. Three-wheelers are popular among low-income groups due to the lowest selling price [1]. Normally, the 4-stroke three-wheeler comes with a manual transmission system with 4 forward gears and 1 reverse gear. However, an automatic transmission three-wheeler is not yet commercially popular in the market. In the automatic transmission, there is more comfort during driving situations as it can provide a smooth driving experience and can minimize day-to-day driving difficulties in hills, traffic, or instances where rapid gear shifting is required [2].

Automatic transmission vehicles are very popular in the present market due to their faster gear changing, lack of manual shift gears, improved drivability, and overall efficiency. According to the researchers, three-wheelers run around 40- 60km per day in urban towns [3, 14]. Due to the heavy traffic, driving a manual transmission vehicle is quite strenuous for the driver (especially for taxi three-wheeler drivers). Additionally, an automatic transmission three-wheeler could be handled by disabled individuals also, as reduced, and simplified driver input requirements compared to a conventional system. Though more than 4.5 million three-wheelers with manual transmission are in use, more researchers focus on conventional vehicle re-design and further development to gain more benefits [4]. Environment pollution by emissions, higher fuel consumption, and lower efficiency are remarked as the drawbacks of conventional vehicles. And, in automatic transmission, it is not required to perform any action to shift to the next gear. It is easy to step on the accelerator pedal and drive. braking is enough to control the speed of the vehicle. However, in manual transmission vehicles, driving is dependent on the driver's ability to drive the vehicle by engaging and disengaging the clutch with the help of the driver's foot. According to those inputs, the gear ratio would be changed. Hence, the driver needs good practice and knowledge to handle these clutch, brake, and accelerator pedals for a comfortable ride. Next, there are a few key performance indicators available for automatic transmission systems to compare with manual transmissions, namely, fuel economy, durability, performance, and control. [5]

The CVT transmission system is an outstanding technology for an automatic transmission vehicle. Lightweight components, infinity gear ratios, quick gear changes, ease of driving, low cost of production, simple configuration, and less regular services are the key benefits of the CVT system. Metal belt CVT and rubber belt CVT systems are the most popular and usable technologies which have energy efficiency ranges from 90 to 97 percent. Drive pulley, driven pulley, and belt drive are the major components of the rubber V-belt type CVT system [6, 13].

Most passenger vehicles are manufactured with automated manual transmissions or automatic transmissions, but the major drawback is that brand-new vehicles are more costly than vehicles with conventional manual transmissions. On the other hand, three-wheelers are not commercially popular with the automatic transmission system, the introduction of automatic three-wheelers could create significant impacts on the market, and it will be one of the biggest challenges to the conventional three-wheeler's marketing strategies [2, 15].

Normally three-wheelers are mainly devoted to serving the middle-income group people. The Highest cost accumulation is the major reason for not being popular or not selling the brand-new three-wheeler with the automatic transmission system [8]. However, the conversion of manual vehicles to automatic transmission systems will not be more expensive than the price of a brand-new three-wheeler. Therefore, this research aims to "Develop a three-wheeler with automatic transmission using continuous variable transmission [CVT] technology (replacing the original manual transmission system) to improve the drivability". introduction of the latest and cost-effective conversion technology, development of a lighter and compact transmission system, improvement of the drivability experience with less fatigue of the driver, improving the fuel efficiency, and providing a safe and comfortable drive for disabled taxi drivers are the objectives of this project.

This paper is based on the 205cc 4-stroke three-wheeler. Based on the user feedback from society, the requirement of a three-wheeler with automatic transmission has been proven. Finally, a rubber V-belt CVT transmission technology was selected mainly to gain 97% energy efficiency through the system [13].

The principle of this conceptual study is based on several strategies. Reducing the weight of the system, applying minimum changes to the original system, the use of already available spare parts as much as possible, and designing a compact frame to utilize space in the engine compartment. Parts from conventional transmission were removed which are useless for CVT and the reverse gear setup was kept as it is because it was connected to the gearbox separately. Instead of fixing a new reverse gear setup, this conventional reverse gear was used. Due to removing unwanted parts from the transmission and adding CVT the transmission balanced the weight of the vehicle without overweighting.

Features of this system include having mechanical spare parts that can be easily replaced when required, and a user-friendly and simple system that can be repaired easily. High-quality materials for custom-made parts and company-verified mechanical spare parts are included while assembling the final system to achieve the lowest operating cost and low maintenance cost with an acceptable level of safety are few to mention [9]. Usually, the CVT system belt needs to be replaced after passing some range of km of the vehicle, which is notified by the manufacturer. Once the driver felt a lack of speed while accelerating than usual, the variator roller weight needed to be replaced. This design is simple, and few mechanical parts are available. Due to this benefit maintenance is periodically occurred. Due to the selection of cost-effective - high-quality spare parts, the operating cost is also low. In conventional transmission systems, clutch cable and reverse cable replacement, clutch plates and pressure plate replacement, lubrication, gear wheel replacement is so on need to be done when required which tends to increase the maintenance and operating cost.

The preliminary stages start from a conceptual design using Computer-aided design software (SolidWorks) and ensuring the product part's quality and behavior under real-life conditions by using FEA software (ANSYS). Based on the set of calculations, the exact dimensions of required parts and equipment were obtained. After completing the unit and integrating it into the conventional three-wheeler, A series of testing procedures were conducted to ensure the developed concept's outcomes. A few remarkable conclusions were made based on this modification, in terms of budget and fuel economy whilst describing the driver's comfortability and safety.

II. METHODOLOGY

The research was completed within several stages, initially created a plan of methodology as shown in Fig. 1., to minimize the difficulties and to be ready with a quick solution when any possible issues occurred. The work started with a conventional vehicle which had an original manual transmission system. Identification of the parts that are needed to be removed from the system was the starting point. Clutch plates, pressure plates, clutch cable, clutch lever, and manual gearwheel setup [except the reverse gearwheel setup] were identified and removed. At this point, a feasible analysis was done to ensure the required components of the CVT system could be fixed with the available components of the conventional system. For this development, more attention was paid to finding the components and parts that are readily available in the market. However, some parts were identified as they needed to be custom-made according to this concept.

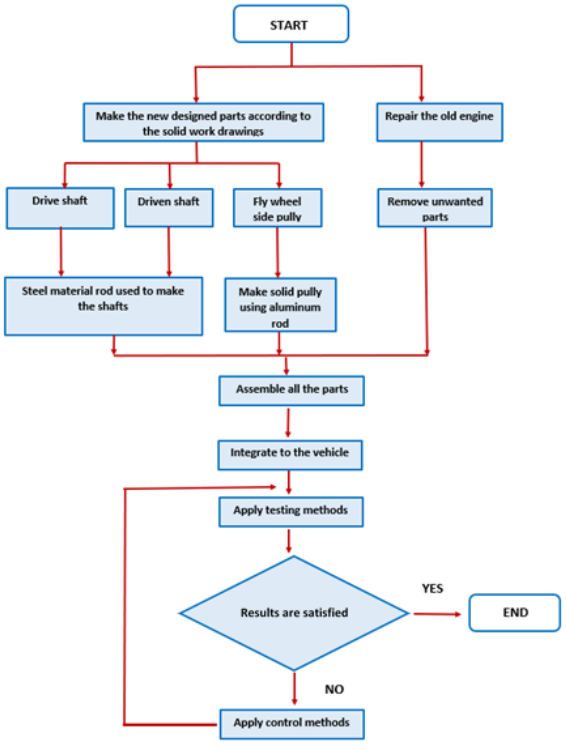


Fig. 1. Progress Flow Chart

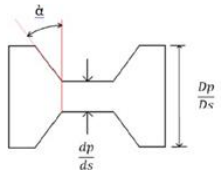
Due to the selection made of the conventional vehicle, the engine was repaired to get the optimal working condition of the vehicle. Meanwhile, calculations were done to determine the size of each component of the CVT [9, 17]. There are a few assumptions made for ease of the calculations. In general, a three-wheeler's odometer shows in the range of 0-80 km/h, a maximum speed is assumed to be 65km/h as an average of a conventional three-wheeler with 3 passengers.

TABLE I. THREE-WHEELER'S SPECIFICATIONS

Description	Value
Maximum torque of the engine	17 Nm
Maximum Power of the engine	7.6 kW
Mass of the empty Vehicle	262.32Kg
Mass of Vehicle with driver	332.32Kg
Mass of Vehicle with driver + 2 Passengers	400Kg
Mass of Vehicle with driver + 3 Passengers	542.32Kg
Maximum r.p.m	5000 r.p.m
Minimum r.p.m	3500 r.p.m
Maximum speed (*V*)	65 km/h
Radius of the tire (front)	0.2m
Radius of the tire (rear)	0.2m
Frontal area	1.5414 m^2
Maximum gradient angle	25º
Density of Air	1.2
Coefficient of drag	0.385
Coefficient of rolling resistant	0.015
Transmission efficiency (ŋ)	0.85

From the data, available as shown in above Tab. 1, a few component calculations were performed. Tab. 2 below summarizes the results of the mathematical calculations performed.

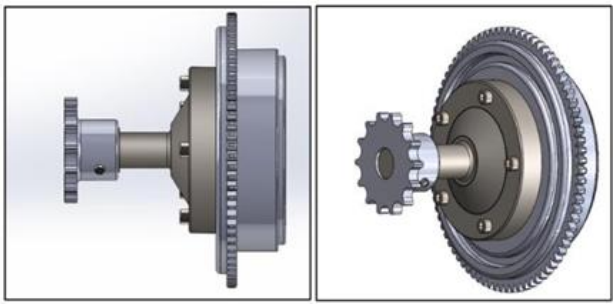
TABLE II. SUMMARY OF THE CALCULATIONS

Description	Results
Speed of tire (N), at 65 km/h	861.82 r.p.m
Air resistance (*Fd*)	114.49 N
Rolling resistance (*Fr*)	79.80 N
Gradient Resistance (*FG)*	2048.39 N
Tractive Effort (*TE*)	2242.68 N
Torque	448.53 Nm
Higher gear ratio (Transmission)	5.27
Lower gear ratio (Transmission)	0.45
Higher gear ratio (by CVT)	5.89
Lower gear ratio (by CVT)	0.48
CVT Pulley sizes (as per the Market research)	*Dp* = 107 mm *dp* = 24 mm *Ds* = 141.5 mm *ds* = 52mm
The center-to-center distance of pullies.(to determine the Belt length)	530 mm
Chain drive gear ratio	1.7:1
	$\dot{\alpha}$ = half wedge angle (20º) Dp= dia: of the larger primary pulley dp= dia: of the smaller primary pulley Ds= dia: of larger secondary pulley ds= dia: of the smaller secondary pulley

Fortunately, the available size of the CVT components is matched with the required size for this concept. As shown in Tab. 2, the three-wheeler's engine required a higher gear ratio as given in 5.27 and a lower gear ratio of 0.45 which can be achieved by using this selected size of CVT pullies. This CVT provides 5.89 as a higher gear ratio and 0.48 as a lower gear ratio. That made it easy to advance the concept beyond the prototype model.

After the selection of the required CVT system components was done, the next stage was to design the new components namely, the chain drive shaft, driven shaft, and drive shaft of each pulley. According to the selected part's dimensions and requirements of the system, all the shafts were modeled by using Solid Work Software as shown in Fig. 2., Fig. 3., Fig. 4., and Fig. 5. and the shafts were tested according to Finite Element Analysis by using ANSYS 2022 R1 software as shown in Fig. 6., Fig. 7., Fig. 8. to ensure the physical behavior of the shafts as in real-life conditions.

Fig. 2. Flywheel assembly.



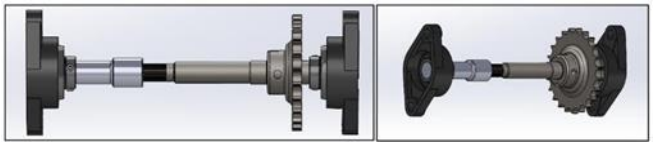


Fig. 3. CVT drive shaft assembly.

Fig. 4. CVT drive shaft – Primary pulley shaft.

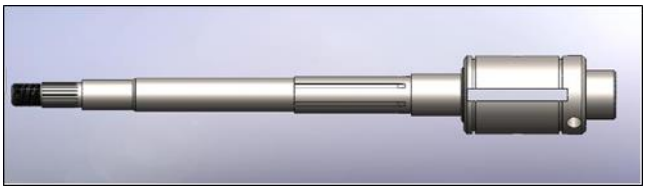


Fig. 5. CVT driven shaft – Secondary pulley shaft.

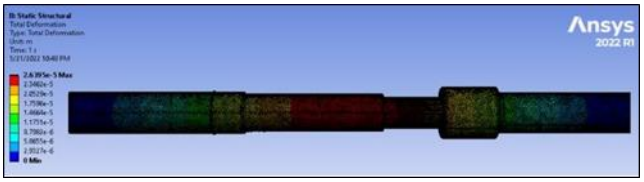


Fig. 6. FEA of CVT drive shaft.

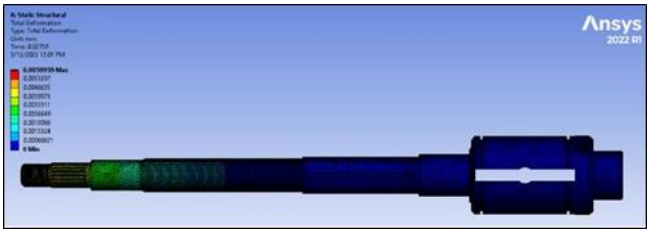


Fig. 7. FEA of CVT driven shaft.

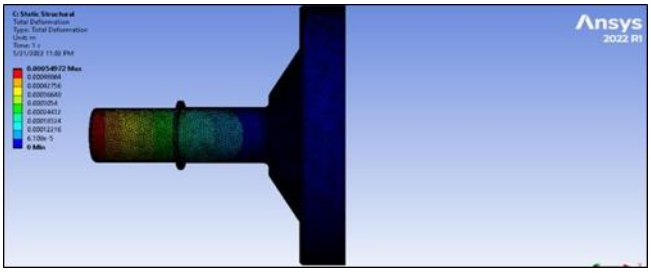


Fig. 8. FEA of Flywheel shaft.

Under Finite element analysis – FEA, Total deformation, elastic strain, and equant stress were analyzed mainly for each shaft. Once the simulation results were highly satisfied, shafts were constructed using AISI 1035 steel as per the design.

In the design stage, A trial-and-error approach has been used for the fixing of components where the appropriate means have been identified. Because of the available resources of the market and space utilization of the engine bay, the chain drive mechanism that can transfer the engine power to CVT was added to the design. In the end, the drive shaft location was changed from the original vehicle design. While the driven shaft is not changed. The chain drive mechanism is fixed on the flywheel as shown in Fig. 2.

II.I Power Transmission

The power flow of the assembled final system can be defined as a driver who can control the acceleration lever (throttle position) which is fixed on the steering handle of the three-wheelers. Then the engine produces power to move the vehicle. As usual, engine power is taken directly from the crankshaft to the flywheel. According to the flywheel rotational speed, the shaft that connects the flywheel will also be rotated. Two sprocket wheels, one from the flywheel's side and the other from CVT's primary pulley side are connected by a chain drive that can transmit the power from the flywheel shaft to CVT's primary pulley shaft. Hence, CVT gets power from the engine now as shown in below Fig. 9. The primary pulley and secondary pulley of CVT were connected via a rubber V belt. Then finally, power is transmitted from the secondary pulley to a differential unit of the engine.

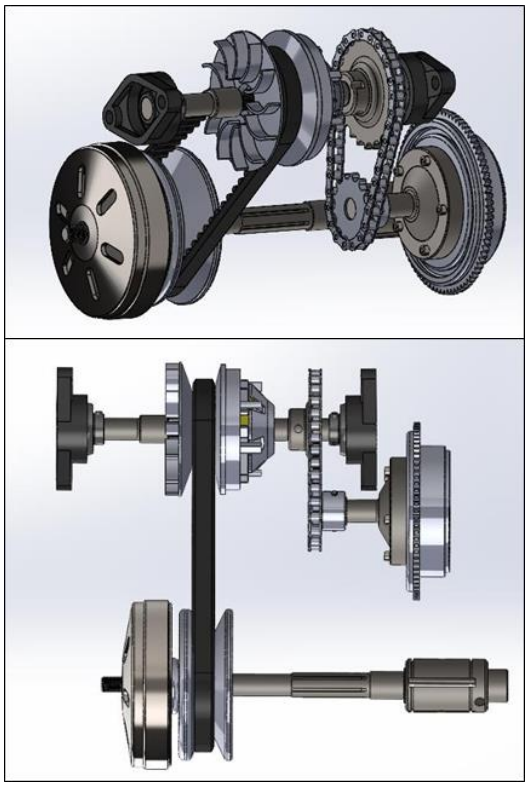


Fig.9. Final 3D design of the concept

The primary pulley of the CVT contains a ram plate, roller weights, variator plate, and front plate. The front plate is fixed while the variator plate can only move. When this shaft is rotating, roller weights will move from the center of the plate outwards. This moment will induce the centrifugal force along the curved surface. When the roller weights are moving, the variator conical plate will move meanwhile the ram plate is in a fixed condition as shown in Fig. 10.

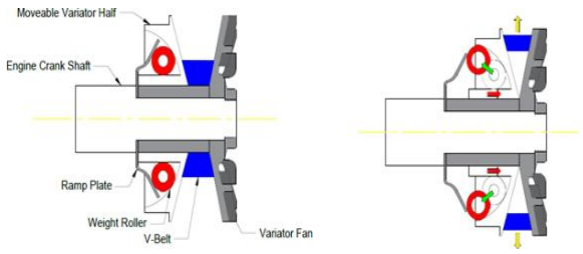


Fig. 10. The behavior of the Roller weights

The belt drive will be under friction to rotate both pullies. The secondary pulley which is consisting of the clutch bell housing, outer and inner conical plates, center spring, centrifugal clutch assembly, etc. One of these plates is fixed and another one is capable of moving. The clutch assembly consists of weighted arms which are connected to the

secondary pulley. When the speed is over the ideal speed, or in other words, when sufficient speed is reached, this weighted arm will swing outward causing the centrifugal force. Weighted arms consist of friction pads that are engaged with the clutch bell housing. Thus, the clutch bell housing will get the speed of the system to rotate. At the end, the secondary pulley will transmit the power to the wheel through the final gear setup of the transmission system.

This system should fix the chassis of the three-wheeler. In a three-wheeler, the engine is located at the rear side. The frame was made by using iron metal plates (8mm thickness) and mild steel square rods (thickness 6mm). This frame needs to only hold the primary pulley assembly. Therefore, the use of steel plates and rods is a compact way to reduce the weight of the system.

The final stage of designing is the testing procedure. The CVT system is absent with a neutral gear which is only available with the manual transmission system. Once the vehicle completely stops and brakes are applied, in this situation only the CVT system can activate the neutral gear. When starting the vehicle, press the brake pedal and accelerator gently and start it by twisting the ignition key or pressing the start button. Once the engine is started, release the pressure on the brake pedal slowly meanwhile increasing the acceleration. Normally CVT system is not functioning when the engine is starting which is about the ideal speed of the vehicle, the speed of the CVT system is dependent on the acceleration level. Anyhow, at any time like traffic modes neutral gear requirement arises by applying brakes that can be achieved. But when thinking about the neutral gear requirement beyond this point, emission testing occurs. The engine emission tests needed to be done by accelerating the vehicle up to some RPM level. This traditional three-wheeler can be tested by having the vehicle in a neutral gear position, but in the CVT system due to the absence of a neutral gear that could not be carried out. If it is needed to be added to this system, that would require fixing a separate gearbox with the CVT. To keep the design simple and compact this idea was not considered. Anyhow, to solve this drawback of this concept, one suggestion has been elaborated here. As shown in Fig. 11., the three-wheeler's engine and transmission system will automatically be in the neutral position when lifting one rear wheel from the ground at the same time the other two wheels should be on the ground. Finally, the three-wheeler was in the neutral position and able to conduct the emission test. Driver normally keeps vehicle jack while driving for any unexpected or instant repairing purposes.

Fig. 11. Tire lifted to get the neutral condition.

II.II Test the System

One of the major factors affecting the CVT system is gear transmission efficiency which can be defined by CVT pulley diameter's changing capacities. The changing of the gears automatically is done by the diameter variation of each pulley [8, 17].

To ensure the pulley's diameter variation, one technique was elaborated. Firstly, dismantling the CVT primary pulley assembled from the holding frame. By using a marker pen, an Ink mark was drawn on the variator plate surface as a visible line that can be easily erased. The displacement in full acceleration is measured depending on the weight of the roller and the rpm of the engine. As shown in Fig. 12., after the full acceleration was completed, the ink line was erased up to this level. This test was used to determine the belt rising level at high acceleration.

Fig. 12. Ink mark to determine the belt rising level

To conclude the value of this research to the market, a survey-based study has been carried out to identify further improvements and suggestions for the developed mechanism from the end users.

III. Results and Discussion

To compare the features, both systems were subjected to similar experiments. The newly developed automatic transmission three-wheeler and conventional transmission three-wheeler were driven on a selected road. When the vehicle runs in a flat road condition it reaches 24 km/h with two passengers on board at the high speed of the three-wheeler in flat road, right this time the accelerator is also pressed at its highest level to provide full throttle to the engine. The driving experience was found to be smooth and unnecessary vibration or noises were not observed. Vehicle sound is also normal as in the case of a conventional three-wheeler. The gear changing is done smoothly without any fluctuations, delays, unnecessary vibrations, or shocks.

Under hilly road conditions, the vehicle reached 14 km/h as a top high speed with two passengers while 18 km/h was its top speed without passengers and goods. Right this time, Testing was done by providing full-throttle conditions. When the road traffic situations, a three-wheeler can keep the engine running in idle whilst the three-wheeler is stopped, also, when it is required to drive immediately, smooth acceleration was observed. The CVT was able to change speed and torque by itself smoothly when the driver provided inputs or commands for acceleration and brake. The pickup speed of the CVT system is at a satisfactory level as it was able to reach the highest of 24km/h speed in 13 seconds by providing the full throttle and this system can keep the vehicle in idle condition by providing low throttle same as in the case of the neutral position of the original manual transmission system.

Once the engine is started that engine power will not force to move the vehicle if the vehicle is parked on a flat surface which is like a conventional manual transmission three-wheeler under neutral gear. But when starting the engine, the driver needs to apply brake until the engine gets started. Once the acceleration is gradually increased by the driver which causes the vehicle to start, then move.

This developed CVT three-wheeler is also able to reverse the vehicle as in the case of a manual transmission-based system. Reversing speed also reached up to 22 km/h. No excessive vibrations, no shocks, no unwanted noises, or delays occurred when trying to reverse the vehicle. The torque and speed changes were also smooth while reversing as well. In this vehicle, a conventional reverse gear setup was used without any changes which comes as separate from the manual transmission.

The driving comfort of the developed system is a different experience for passengers when compared with manual transmission three-wheelers. Driving is also easier than manual transmission, no effort needs to be made to change the gears, and it would automatically change as per the driver's requirements when depressing the acceleration pedals. CVT provides infinity gear ratios.

In terms of fuel consumption, this three-wheeler with the original transmission system (before changing to CVT transmission) worked at 30 km per 1L of petrol. After changing this from a manual to an automatic system, it was tested to be at 22 km per 1L. But fuel consumption was higher than with the original transmission system in an unexpected way.

To realize the reasons behind low speed and high fuel consumption, some techniques were incorporated. The primary pulley's major components are the set of six flyweights and the moveable sheaves as shown in fig.10. When the engine speed is gradually increasing, the six flyweights (rollers) tend to swing and generate a force that works on the ram plate of the primary pulley, reducing the gap between the ram plate and the variator. As the contact ratio of the belt rises in the primary shaft, the gear ratio rises as well. More force will be delivered to the ram plate of the primary pulley in CVT by producing a heavier roller, pulling the rear pulley forward more quickly. If the roller weights are heavy, the gear will be required to act at a high speed. As the mass of the roller rises, so does the centrifugal force in the primary shaft, which transmits power and torque through the belt.

Fig. 13. Two types of the Roller weights

In the analysis of speed, the impact of the roller set's weight on the speed of the vehicle was compared. Two different sets of roller weights with diameter variation have been selected as shown in Fig. 13. and compared in case of full throttle position. With higher-weight rollers which weighed 105.54g, the belt drive is raised to 21.5mm out of 41.5mm of the completely higher diameter of the variator pulley while the low-weight roller set which is weighted at 83.70g belt rises to 33.47mm out of 41.5mm of the complete diameter of the pulley. It differed from around 11.97mm distance. By using this procedure, finally realized that the weight of the roller weights is completely corporate to change the gear ratios. But these weight changes rollers weights would not improve the speed of this three-wheeler as well as reduce the fuel consumption. Because these two roller weights did not reach 41.5mm of the complete diameter of the pully to get to the optimum working condition of this CVT system. These roller weights are purchased from different manufacturing companies; thus, each roller weight has a specific RPM value and torque capacity to achieve the optimum condition of CVT. The lower weighted roller set which is 83.7g works with 7000rpm, and the higher weighted roller set which is 105.54g works with 8000rpm. But three-wheel 4 strokes with 205CC engine have 5000rpm as higher rpm than information provided by the manufacturer. However, this developed vehicle has made some differences when compared to the original vehicle conditions. To investigate the exact RPM of the developed system vehicle, an engine tachometer was used. The top RPM was noted as 3139 rpm by providing a full-throttle acceleration. Due to the lack of the vary roller weights in the market, could not find the exact matching roller weight to this development. This is the major reason behind the reduced performance of the system. It tends to cause high fuel consumption, slow speed while riding and made some difficulties in hill climbing also.

If these required gear ratios could be achieved with low acceleration input, then it can be assured that it will improve fuel consumption. This roller set is resistant to rollover completely with 3139 rpm while providing full throttle conditions to drive the vehicle. If the three-wheeler is driving on a flat road surface, low acceleration input is almost enough to drive the conventional vehicle, but this newly designed transmission system, always needs to provide full throttle to drive the vehicle even on the flat road due to available roller weights are not able to work with this 3139rpm. Once the rpm properties of the roller weights are completely matched with the engine rpm, able to manage the throttle conditions as in utilized level. Otherwise, fuel consumption automatically will be higher than manual transmission systems.

The secondary pulley center spring needs to be checked according to this system's required rpm level. The spring, which is used here works for 4000 rpm but still, it provides good performance for 3139 rpm. The effect from the secondary pulley spring is more acceptable than roller weight, as this spring was tested and became satisfied with the performance as expected.

IV. Conclusion

Three Wheelers is a compact budget vehicle that comes with a manual transmission system, which is very popular in Sri Lanka. Meanwhile, the automobile industry tends to manufacture automatic drive vehicles with more advanced

technologies. Due to various advantages offered by automatic transmission namely, comfortable ride, less effort to handle the vehicle, ease to practice driving for anyone, suitability for disabled people, suitability for urban traffic area driving, etc. This research was aimed towards converting the manual transmission three-wheeler into the automatic transmission three-wheeler. Therefore, the CVT system with a rubber V-belt was selected instead of using another type of technology. This design was based on a compact light design with minimum changes to the original system, to stay within limited space in the engine bay of the three-wheel and low torque vehicle, this rubber V-belt type was selected. The major reason to select the rubber V belt, it is high energy efficient than the metal belt. By utilizing available resources, spare parts, etc. in the market, the design was done. According to the set of mathematical calculations, the parts and equipment were selected. Then all the components as per the design are mounted to the three-wheeler's chassis, and the research's aim and objectives which are defined already are clarified through the experiment tests. According to the collected results, the highest speed of the vehicle can be defined as 24km/h, and it was found to be somewhat difficult to perform a hill climbing drive. The reverse drive was also achieved as similar to the original vehicle without changing the original reverse gear design. The cornering drive also performed without any performance issues with the CVT transmission system due to the unchanged differential part of the conventional vehicle. Therefore, it could be stated that this research became a success, whilst providing comfortable drive, less fatigue for the driver of the vehicle, ease of the drive, suitability for disabled drivers, and lightweight compact design which are included in the objectives also achieved. However, the speed of the vehicle, hill climbing performance, and fuel consumption need to be improved once again by changing the specifications of the roller weights by matching with the engine rpm to enhance the newly developed 4-stroke 205CC three-wheel with the cover of all the equipment to protect them from dust and contaminants.

ACKNOWLEDGEMENTS

We acknowledge the support of Mr. T. Luxshman, and Mr. R. Eragan (Technical Officers, Department of Engineering Technology, University of Jaffna.) for their dedicated service in accomplishing this study.

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2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

High-Efficiency Buck DC-DC Converter Using Automatic PWM/PFM Mode Control Based on Load Current Variation with Digital Soft Start

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***Abstract*—This paper proposes a dual-mode buck DC-DC converter that operates alternately between Pulse Width Modulation (PWM) and Pulse Frequency Modulation (PFM) modes, achieving high efficiency over a wide load range, making it suitable for applications in the Internet of Things (IoT) and biomedical technology fields. The zero-current detector (ZCD) technique is utilized for the purpose of eliminating negative current when the inductor is in a discontinuous conduction mode (DCM) state. It simultaneously transitions the converter into pulse frequency modulation (PFM) mode to reduce power losses under light load conditions. The converter utilizes current sensing to detect the inductor current in continuous conduction mode (CCM) and switches operation to PWM mode, achieving peak efficiency under high load currents. To ensure a precise and stable operation with fast response during operation this paper proposes a rail-to-rail comparator with wide bandwidth, combined with an efficient soft-start technique. Special, during operation, to mitigate the phenomenon of shoot-through caused by PMOS and NMOS at high frequencies, dead-time techniques are applied to avoid this issue. The converter is designed using 180 nm CMOS technology and achieves a peak efficiency of 96% with VDD = 3.3 V (standard battery voltage) and V_{OUT} ranging from 1.2 - 1.8 V. The load current advantageously spans from 250 - 3.5 mA, with load values ranging from 5 - 400 Ω. The switching frequency varies from 1.1 - 0.05 MHz, and the time for output voltage recovery between the two modes is 10 and 8 μs when transitioning from heavy to light load and vice versa.**

***Keywords*—DC-DC converter, on-chip, discontinuous conduction mode, continuous conduction mode.**

I. INTRODUCTION

The increasing demand for power management integrated circuits (ICs) is driven by the growing popularity of portable electronic devices. These ICs, especially buck DC-DC converters, play a crucial role in converting battery supplies into regulated voltages, supporting the advancement of battery- powered portable applications. [1-3]. High-efficiency buck DC-DC converters with a wide load current range are required to increase battery life. In reality, the pulse width modulation (PWM) scheme has high efficiency in heavy load because conduction loss, switching loss, and quiescent loss are relatively smaller than output power, whereas the pulse frequency modulation (PFM) scheme has high efficiency in light load because quiescent loss and switching loss are reduced by reducing switching frequency and selecting a small switch transistor size [4]. As a result, the study of PWM, and PFM dual-mode buck converters has long been a hotspot [5-7]. The PWM/PFM double buck converter is often made of a PWM modulation and a PFM modulator, which adds to the circuit's complexity [8]. Moreover, in PFM mode, the error amplifier is often switched off to decrease power dissipation and hence improve efficiency. As a result of the extended settling time of the error amplifier, the undershoot voltage is significant and the recovery time is protracted when the converter switches from PFM to PWM mode.

The Power Management Integrated Circuits (PMICs) are essential components that need to operate with high efficiency while consuming minimal energy. In battery-powered devices, battery replacement is often impractical, therefore optimizing power usage and load current is crucial to extend battery life. Because, there is a growing need for adaptive voltage converters capable of operating in both PWM (Pulse Width Modulation) and PFM (Pulse Frequency Modulation) modes, switching automatically based on the load conditions. These modes operate differently depending on load variations. In high-load conditions, as shown in Fig. 1(a), the converter operates in Continuous Conduction Mode (CCM) is inductor current never goes to zero during the switching cycle and continuously charged and discharged at a very high frequency. This maintains a stable current in the inductor, controlled

by the PWM voltage control mode, this mode enables a fast response of the output voltage, and stability, minimizes power losses in the switch, and efficiently transfers energy from the input to the output, achieving maximum efficiency with heavy loads. In contrast, at light-load conditions, as depicted in Fig. 1(b), the converter operates in Discontinuous Conduction Mode (DCM) using PFM control, this inductor current becomes discontinuous, meaning there are moments during the switching cycle when the current I_L drops to zero before the cycle ends. In mode PFM control, the switching frequency is adjusted based on the load, when the load is light switching frequency is lowered to reduce power losses in the inductor and switch, improving efficiency at light loads. However, in this mode, it is less stable compared to heavy load conditions.

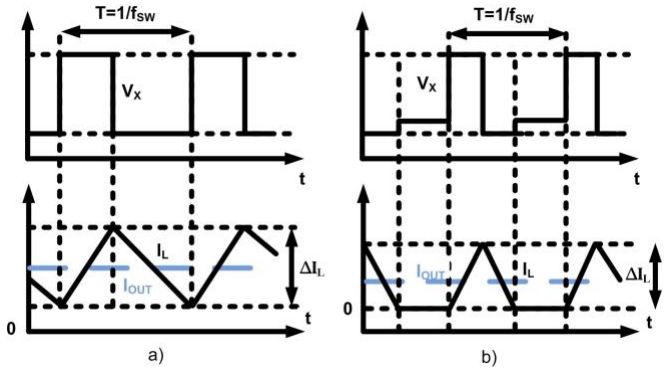

Fig. 1. (a) Inductor current of the DC-DC converter in mode CCM and (b) mode DCM operations

By combining both PWM and PFM control modes, a voltage converter can leverage the strengths of each mode and mitigate their weaknesses. This versatility allows the converter to adapt to varying load conditions effectively. Therefore, selecting the appropriate mode based on the specific load requirements is crucial for optimal performance. Such adaptive voltage converters play a vital role in extending the lifespan of battery-powered devices and optimizing their energy usage, making them a valuable solution in various applications.

II. Structure Buck Dc-Dc Converter with Pwm/Pfm Control Technology Combine with Soft Start

The buck converter averages the input voltage to produce a rectified output voltage. The buck converter in CMOS technology is similar but requires high accuracy, fast speed, high conversion efficiency, and a small chip area to meet applications in biomedical engineering. It works thanks to the switching frequency and the dominant characteristic of the inductor, from an input voltage through the buck converter, the output voltage is reduced. The output voltage will be changed when switching ON/OFF states S1/S2, adjusting the on/off time of switch S1/S2 causes the average output voltage to change according to the TON/TOFF cycle of S1/S2. When switch S1 is ON and S2 is OFF, current enters the inductor, the magnetic field in the inductor increases, the current in the inductor is negative, so the energy in the inductor is high, and the output voltage is low. When S1 is OFF, S2 is on, providing a ground current path, and the direction of current in the positive inductor supplying current to the output voltage load is increased. The two processes operate continuously, the output voltage of the converter is the average voltage of the two on-and-off processes S1/S2 over time. The output voltage is stable and can be adjusted within a certain limit. This paper implements a feedback control system for the on-off switching cycle of the switch.

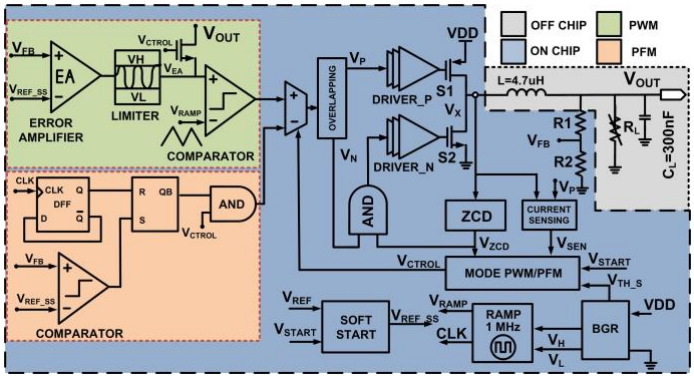

Fig. 2. Structure buck DC-DC converter using PWM/PFM control combined with soft start.

Fig. 2 depicts a buck DC-DC converter with PWM/PFM control and soft start. The PWM modulator and PFM modulator are combined using MUX to control the buck converter in either PWM or PFM mode. MUX is controlled by the V_{CTROL} signal to switch between the two modes, with logic '0' representing PWM mode and logic '1' representing PFM mode. The buck converter performs automatic mode switching based on the signal V_{CTROL}, which is set by a load current sensor. The V_{CTROL} has a state logic '0' when the load is light and '1' when the load becomes heavy.

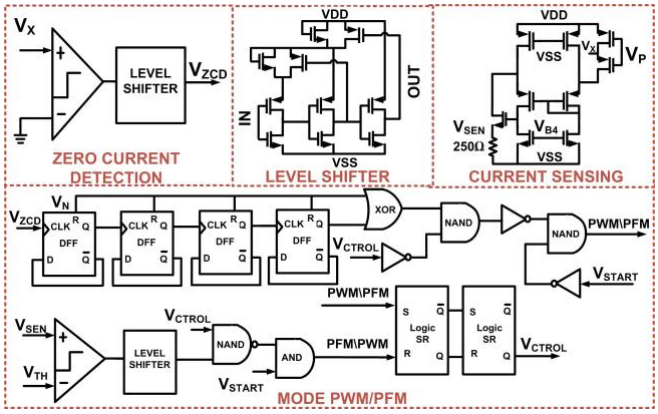

Fig. 3. The architecture of mode control PWM/PFM

Fig. 3 shows the PWM/PFM control block mode conversion block which detects the output current of the converter and

switches between PWM and PFM modes as necessary to optimize efficiency and performance. This helps to ensure that the converter operates in the most efficient mode based on the load conditions. This block is responsible for detecting the output current of the converter and includes detectors for PWM-to- PFM and PFM-to-PWM modes. The switch frequency is 1 MHz in PWM mode and 50 kHz in PFM mode. The Zero Current Detection (ZCD) block functions to detect the negative current I_L flowing in comparison to ground 0 V when S2 is open. If the output load is high, the output current will be low, and I_L will operate in DCM (Discontinuous Conduction Mode). At this point, the V_{ZCD} signal affects S2, preventing I_L from discharging into the negative current, and the current in the output capacitor is discharged only through the load. The signal comparing V_X to ground is passed through a LEVEL SHIFTER block to generate the V_{ZCD} signal with a high level, controlling the transition from PWM mode to PFM mode of the Buck DC-DC converter. The current sensing block is designed to detect fluctuations in the current at V_X, which is generated by the resistance of S1. The V_{SEN} signal increases and decreases in response to changes in the input current. The accuracy of V_{SEN} and the performance of the comparator circuit are crucial for the precise operation of the conversion system. The system switches from PFM mode to PWM mode based on the value of V_{SEN}.

The switching time between the two modes must differ by a 10μs interval, denoted as T_{ns} showed in Fig. 4 because the two modes switch at different load current values to prevent misinterpretation and continuous mode switching. The signal transitioning from high to low signifies a transition from PWM mode to PFM mode, whereas the signal transitioning from low to high indicates a shift from PFM mode to PWM mode. The PWM/PFM mode block operates quite accurately within a load current range spanning from 250 - 3.5 mA.

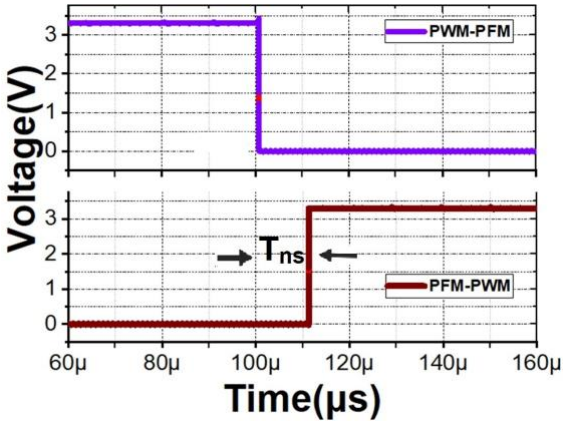

Fig. 4. The simulation waveforms of the proposed mode control PWM/PFM

The error amplifier consists of an error amplifier block along with a capacitor multiplier block, as shown in Fig. 5(a). The output voltage is fed back to the feedback block, where the feedback voltage V_{FB} is compared to the reference voltage

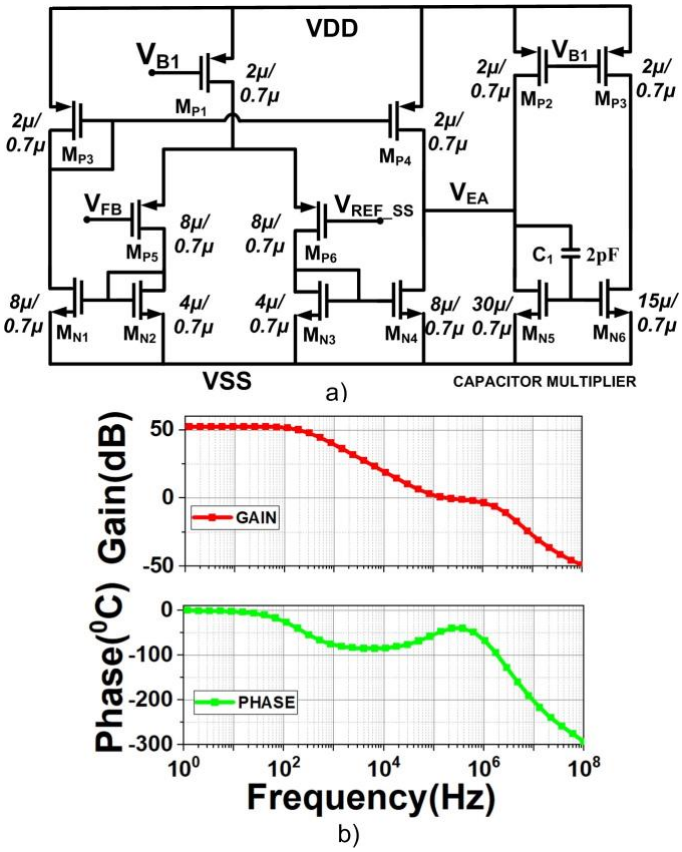

Fig. 5. (a) The architecture of error amplifier, (b) simulation gain phase

V_{REF_SS} through the error amplifier. The output voltage V_{EA} changes in response to V_{FB}, with a faster response due to the amplification factor. When V_{FB} decreases, V_{EA} decreases, and vice versa. The Operational Transconductance Amplifier (OTA) structure of the error amplifier operates with a gain of 50 dB and low power consumption to ensure the output signal. The application of the capacitor multiplier is to establish the static working point for stabilizing the V_{EA} signal while reducing the size of the capacitor. The VB1 points provide a reference voltage to create a current source for the circuit. Similar to a Type II Compensator, the capacitor multiplier uses an OTA to ensure the stable operation of the error amplifier, controlling the current flowing into the capacitor to maintain the stability of the V_{EA} signal without requiring a large capacitor size. The total circuit current consumption is 2 µA, supplied with a voltage of 3.3 V, and the power consumption of the error amplifier circuit is 6.6 µW. Fig. 5(b) illustrates the gain and phase characteristics of the error amplifier.

The architecture limiter V_{EA} showed in Fig. 6(a), includes two OTA comparison circuits connected together with V_{EA} limited by V_H and V_L, which are the upper and lower thresholds of the V_{RAMP} triangular wave. During start-up and mode switching, the V_{EA} circuit changes if it reaches V_H. At that time, M_{P10} is turned on, causing the V_{EA} voltage to drop below V_H, and then M_{P10} is turned off again capacitor C_3 ensures the

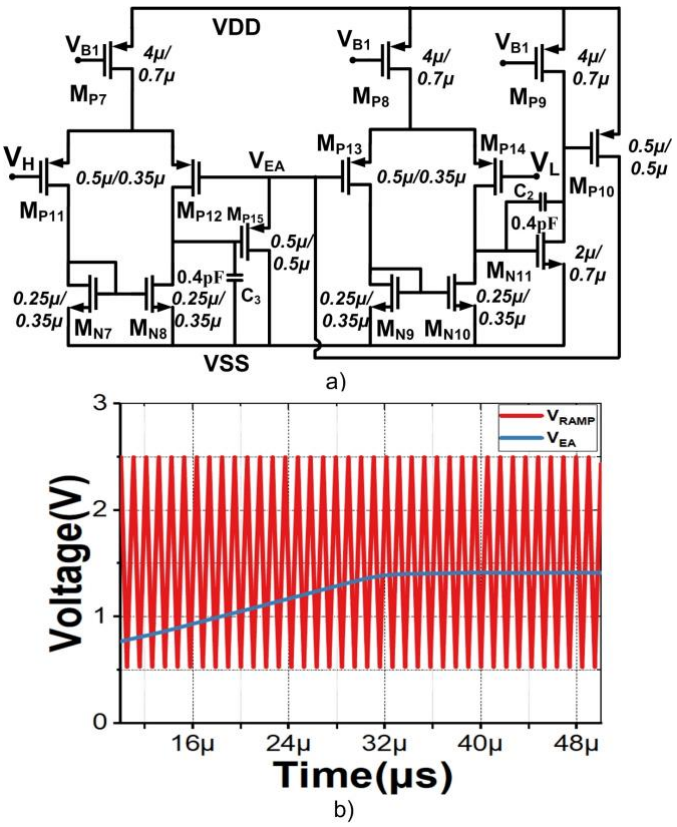

Fig. 6. (a) The architecture of limiter, (b) simulation limiter signal V_{EA}.

opening and closing process of M_{P10} is smooth, and V_{EA} does not exceed V_H. Conversely, if V_{EA} drops below V_L, M_{P15} is turned on, pulling the V_{EA} voltage up to a level greater than V_H and not dropping below the V_L threshold. Since V_L is a low voltage, an additional stage is needed, combined with capacitor C_2, to stabilize the opening and closing of M_{P15}. The V_{EA} limiting block ensures that the converter always stabilizes the V_{EA} signal within the limits of the triangular wave as shown in Fig. 6(b), creating the switching cycle of switches S1 and S2. Without the limiting block, the capacitor generating V_{RAMP} would have to be large, which could affect the size of the chip. Moreover, when the triangular wave limit is smaller, the rate of change of V_{EA} will increase, and the switching frequency cycle of the switch will change rapidly. This will significantly improve the stability time of V_{OUT} during operation or during load changes.

Fig. 7 shows the proposed architecture comparator rail to rail, the comparator is an essential component in a buck converter circuit. The accuracy of the comparator affects the conversion efficiency of the circuit. The conventional comparator consists of a PMOS or NMOS differential pair with low accuracy and input range dependent on the Voltage threshold of the NMOS or PMOS. To improve the accuracy and increase the bandwidth of the comparator, this paper proposes a rail-to-rail comparator without a clock signal. The circuit has the advantage of reducing noise on the comparator, and the input

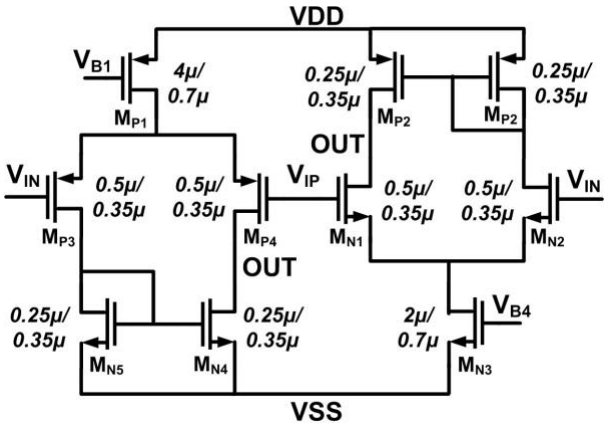

Fig. 7. The architecture of comparator rail to rail

range is not limited by the Voltage threshold of the PMOS or NMOS. This is because the input signal is applied to both

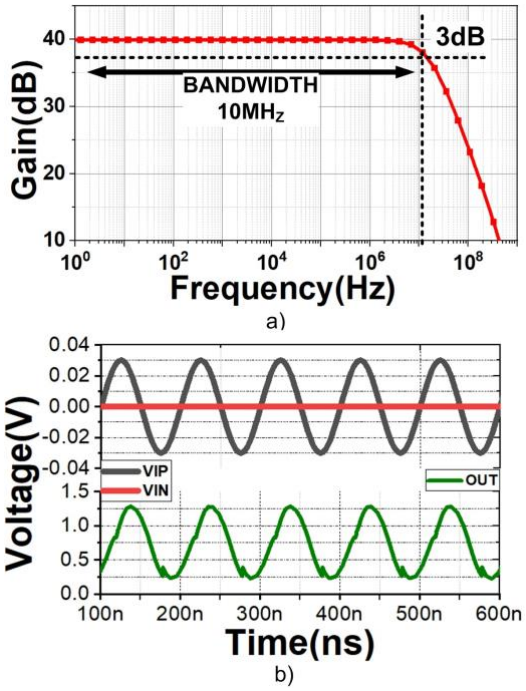

Fig. 8. (a) The simulation waveforms of bandwidth and (b) signal output comparator.

PMOS and NMOS at the same time, which can overcome this limitation. Additionally, the circuit can be compared at a frequency of less than 10 MHz based on bandwidth frequency Fig. 8(a), giving a sine wave signal with a frequency of 10 MHz amplitude of 25 mV to obtain an output signal in Fig. 8(b). In addition, the comparison speed of the circuit also depends on the current flowing through M_{P1} and M_{N3}. The larger the current, the faster the comparison speed. Fig. 9 shows the architecture of the soft start circuit which has an important role in smart electronic devices, especially in biomedical technology where startup circuits require high

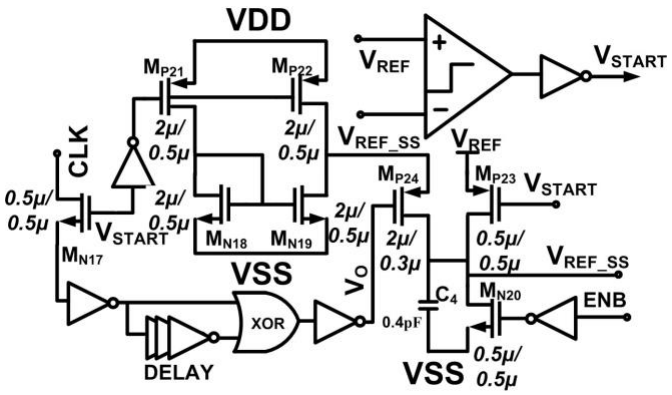

Fig. 9. The architecture of soft start

stability and precision. This paper proposes a simple control technique utilizing charging current and the time it takes to charge a capacitor to determine the startup time of the DC-DC converter. The charging time of the capacitor depends on the current flowing through M_{P24} into the capacitor for each CLK pulse delay. After the V_{REF_SS} voltage increases from 0 V to the desired reference voltage V_{REF} via the signal comparator V_C the CLK pulse is disabled by M_{N17}, and the charging current into the capacitor is cut off by M_{P21} and M_{P22}, while the V_{REF_SS} voltage is maintained at the V_{REF} voltage, as shown in Fig 10.

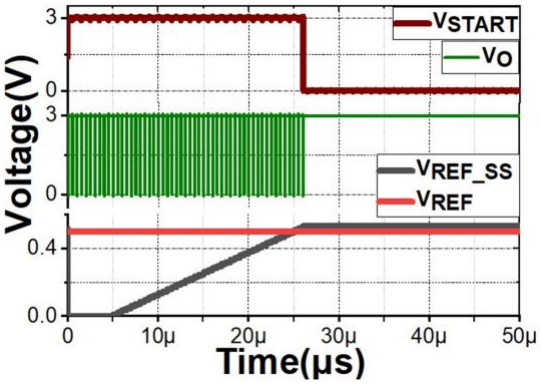

Fig. 10. The simulation waveforms of block soft start

The non-overlapping block serves to create a delay in the control pulses S1 and S2 in a switch. It utilizes the state of cross-connected NAND logic gates, as shown in Fig. 11(a) when one input of the NAND gate is driven to a logic '0', the output always transitions with a rising edge for V_N slower than V_P and with a falling edge for V_N faster than V_P. The remaining NOT gates are used to smooth the signals while increasing the slope for both V_N and V_P. Fig. 11(b) shows the delay time between V_N and V_P during the ON and OFF cycles is designed to prevent S1 and S2 from turning on simultaneously, which could lead to a high voltage touching ground and causing a short-circuit phenomenon. Fig. 12(a), shows the architecture proposed ramp generator circuit, this is a circuit used for

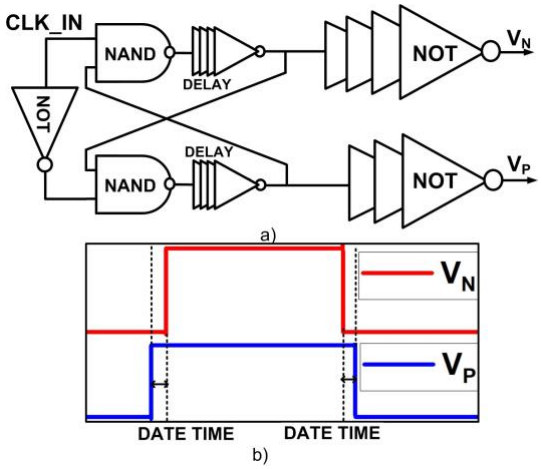

Fig. 11. (a) The architecture of block overlapping; (b) simulation signal V_N and V_P.

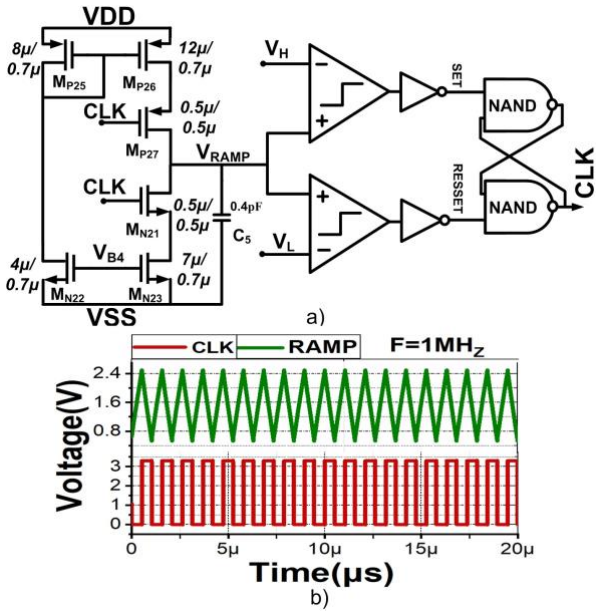

Fig. 12. (a) The architecture of block ramp generator and (b) simulation signal results.

generating a fixed-frequency triangle wave modulation, V_{RAMP} compared to V_{EA} for PWM wave modulation. Additionally, it generates the CLK signal to control soft-start blocks and PFM wave modulation. The V_{RAMP} voltage is created based on the charging and discharging principle of capacitor C_5, which produces a pulse waveform input to the comparator with low voltage V_L and high voltage V_H. During the charging or discharging process, the pulse waveform reaches V_H or V_L, creating SET and RESET signals on the SR latch logic and generating the CLK signal as shown in Fig 12 (b). Fig. 13(a) shows this paper proposes architecture bandgap reference using generates a stable voltage regardless of temperature. The CMOS transistors M_{P31}, M_{P32}, M_{N24}, M_{N25} have the same gate voltage initially. As temperature rises, current through the

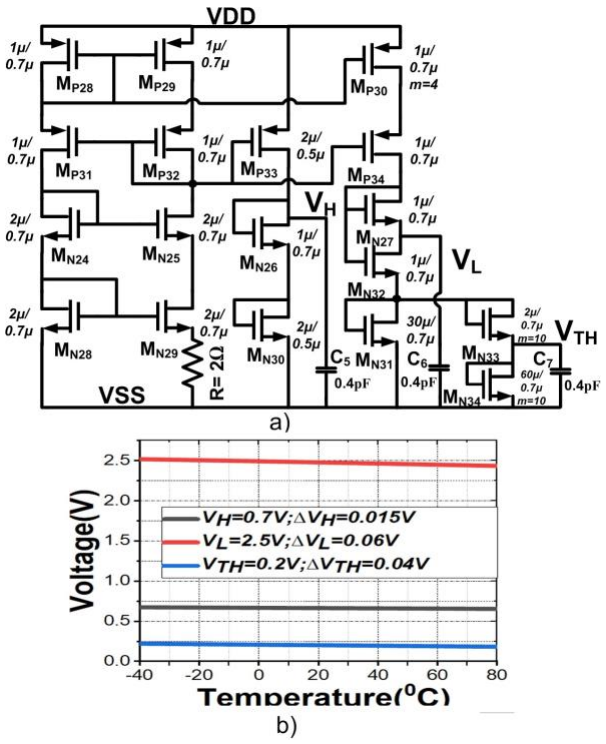

Fig. 13. *(a)* The architecture of block bandgap reference and (b) simulation signal results.

CMOS devices increases, changing the gate voltage values. An increase in gate voltage results in an increase in the resistance of M_{P31} and M_{P32}, while decreasing the resistance of M_{N24} and M_{N25}. The gate voltage will thus vary according to the temperature fluctuation. Fig 13(b) shows points V_H, V_L, and V_{TH} are maintained within a certain temperature range.

III. Results and Discussion

This paper proposes a design dual-mode PWM/PFM buck DC-DC converter implemented in 180nm CMOS technology. The chip layout occupies a compact area of 0.067 mm², as illustrated in Fig. 14. The converter operates in two distinct modes PWM and PFM based on load conditions, providing enhanced efficiency with a peak performance of up to 96%. Additionally, it integrates a soft start block as shown in Fig.9, with a startup time of approximately 25 μs to ensure stability and mitigate noise caused by V_{REF}. The simulation results of load variations in dual mode PWM/PFM buck DC-DC converters are displayed in Fig. 15. The transition between PWM and PFM modes is controlled by the V_{CTROL} signal, with the load current I_L switching from Continuous Conduction Mode (CCM) corresponding to 5 Ω load to Discontinuous Conduction Mode (DCM) corresponding to a 400 Ω load, as shown in Fig. 15(a). Conversely, the transition from PFM to PWM mode is controlled by the V_{CTROL} signal in the opposite direction, switching from PWM to PFM in shown Fig. 15(b). It is noteworthy that in the PWM mode, the converter is considered to be in a sleep state, and the output voltage is

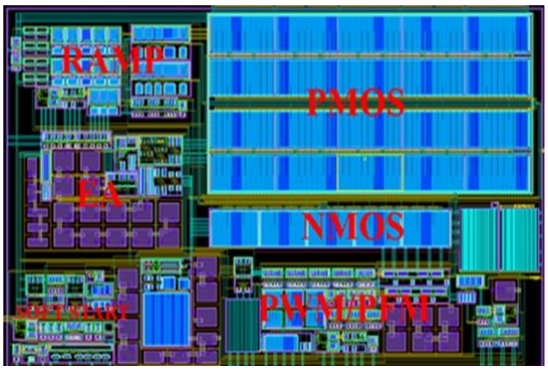

Fig. 14. *The buck converter layout results*

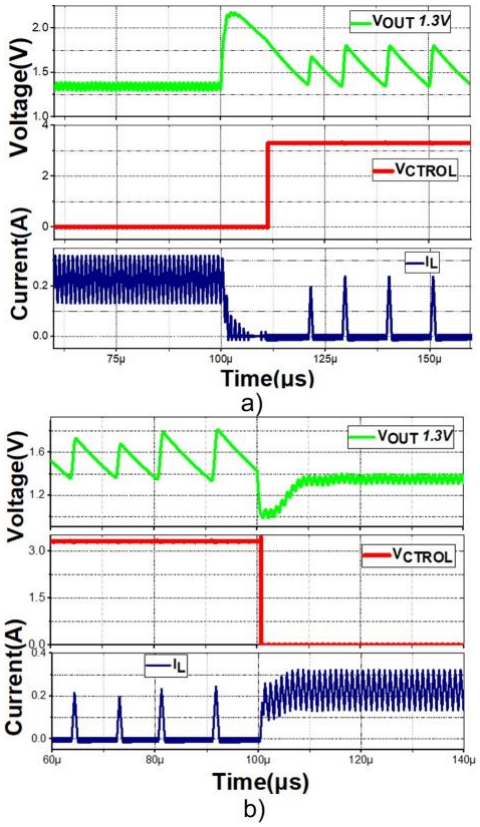

Fig. 15. *(a)* The simulation waveform model switching mode PWM-PFM and (b) PFM-PFM.

unstable compared to the PWM mode where the chip operates at high efficiency.

Fig. 16 depicts the variation in the output current I_{OUT} and input current I_{OUT} as it transitions from a heavy-load mode to a light-load mode have I_{OUT} decreases from 230 to 3.5 mA. By examining the input and output currents, we can calculate the conversion efficiency of the Buck DC-DC converter in shows Fig. 17, allowing us to assess its operational effectiveness. The load resistance R_L will correspondingly change, depending on the voltage values present on it, as shown in Fig. 18. To set the output voltage to different levels within the range of 1.2-1.8 V, switches SW1, SW2, and SW3 are sequentially

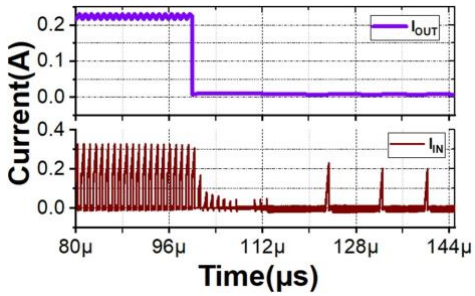

Fig. 16. The simulation current DC-DC buck converter.

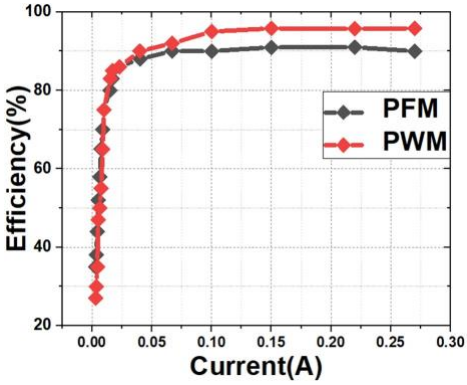

Fig. 17. The efficiently switching mode PFM/PWM.

turned on to adjust the corresponding V_{REF} reference values, as depicted in Fig. 19. The input voltage passes through different resistor networks with varying resistance values, resulting in different V_{REF} values that control the output voltage V_{OUT}. The external circuitry ensures stable operation and chip protection. Performance comparisons with other research are presented in Tab. 1.

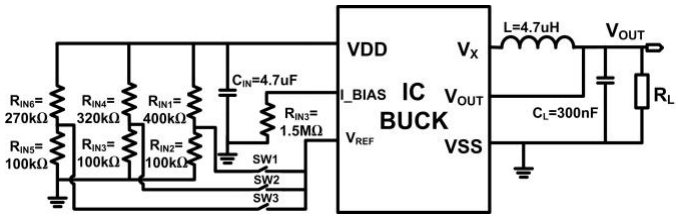

Fig. 18. The diagram of the connection outside the chip of the Buck - DC converter.

TABLE I
PERFORMANCE SUMMARY AND COMPARISON.

Architecture	[9]	[10]	[11]	**This work**
Technology(um)	0.4	0.18	0.35	0.18
Control Loop	PWM	PWM	PWM/PFM	PWM/PFM
Frequency (MHz)	1	0.7	N/A	1/0.05
Input Supply (V)	5	3.3	3.6	3.3
Output Voltage (V)	1.8	2.4	1.8	1.2-1.8
Max Load Current (A)	1	0.25	0.5	0.18
Peak Efficiency (%)	91	94	88	96
Overshoot voltage recovery time (µs)	27	12	28	10
Undershoot voltage recovery time (µs)	31	12	10	8

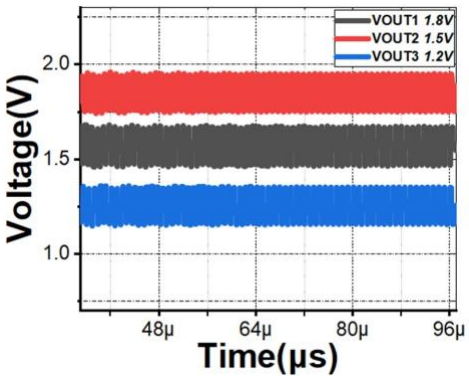

Fig. 19. The simulation output voltage waveform shape in mode PWM.

IV. CONCLUSION

This paper presents a PWM/PFM control technique to improve the output load current variation, combined with a soft-start technique for stable startup of the buck DC-DC converter system, applied in handheld smart electronic devices and biomedical technology. Switching between the two modes of PWM/PFM improves the conversion efficiency over the load variation range. The load efficiency is significantly improved when operating in PFM mode, which helps the converter consume less energy. Simulation results demonstrate that the proposed PWM/PFM control technique can perform automatic mode switching between PWM and PFM modes during the conversion process combined with the soft-start block, the system achieves stable startup.

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2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

Transforming Pediatric Healthcare through Health Informatics: A Pioneering Report of Integrating Laboratory Information System in a Specialized Children's Hospital in Sri Lanka

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***Abstract*—The use of laboratory testing is crucial in the clinical decision-making process. Laboratory errors encompass any deviation that occurs throughout the entire testing process. A Laboratory Information System (LIS) is a software that handles the reception, processing, and storage of information generated throughout the laboratory workflow. A Hospital Information System (HIS) is a system designed to handle healthcare data. Although HIS has been implemented in various hospitals across Sri Lanka, Lady Ridgeway Hospital for Children (LRH) holds the distinction of being the first hospital to successfully integrate a LIS module into their HIS. This integration allowed healthcare providers at LRH to directly order laboratory tests within the HIS and enabled the laboratory to transmit test results directly to the clinicians through the HIS.**

The primary goal of this short report is to assess the benefits received from the use of LIS in mitigating errors in the pre-analytical, analytical, and post-analytical phases of laboratory testing. With the collaboration of both health informatics and laboratory experts, and carefully balancing advantages with drawbacks, the LIS can reduce cost and improve healthcare delivery.

Keywords—Laboratory information system, laboratory testing, health informatics

I. INTRODUCTION

The use of laboratory testing is crucial in the clinical decision-making process. Laboratory errors encompass any deviation that occurs throughout the entire testing process, spanning from test order to the reporting and interpretation of results. Pre-analytical, analytical, and post-analytical phases of the entire testing process are used to categorize laboratory errors. While the pre-analytical phase includes activities from test ordering to specimen delivery, the analytical phase involves the actual testing of the specimen. The reporting and interpretation of the laboratory result is part of the post-analytical phase (Watson & Schoonmaker, 2010). The majority of laboratory errors occur in phases other than the analytical phase (Plebani, 2009). Health informatics interventions can play a significant role in mitigating laboratory errors and reducing turnaround time. These interventions include electronic ordering of laboratory tests, specimen tube barcode labeling, and automated reporting of laboratory test results.

A Laboratory Information System (LIS) is a software that efficiently handles the reception, processing, and storage of information generated throughout the laboratory workflow (McCudden et al., 2020). Its primary function is to automate and streamline the management of all data related to the testing process. A Hospital Information System (HIS) is a system specifically designed to handle healthcare data (Benning & Knaup, 2020). It encompasses various software, hardware, and processes that enable the collection, storage, management, and transmission of a patient's electronic medical record (EMR). Therefore, integration of HIS and LIS significantly improves healthcare delivery by streamlining information flow.

Over the past years, HIS has been increasingly implemented in hospitals in Sri Lanka. Lady Ridgeway Hospital for Children (LRH) is a leading healthcare facility in Sri Lanka specializing in pediatric care. It handles a significant volume of laboratory tests to support the medical treatment of the pediatric population. While HIS has been implemented in various hospitals across Sri Lanka, LRH holds the distinction of being the first hospital to successfully integrate a LIS module into their HIS as a lab module. This integration allows healthcare providers at LRH to directly order laboratory tests from outpatient departments, wards, or clinics within the HIS. Additionally, the two-way functionality of the system enabled the laboratory to transmit test results directly back to the ordering healthcare providers through the HIS, eliminating the need for manual result entry and faster delivery of patient reports.

This short report focuses on assessing the challenges faced during LIS implementation and its impact on healthcare delivery at LRH.

II. Pre-Implementation Assessment

Automation and the advancement of health informatics have drastically changed medical laboratories. There was a significant advancement in its laboratory capabilities at LRH by purchasing high-capacity automated analyzers for clinical chemistry. Despite having high-quality laboratory equipment, there were still numerous manual procedures in place. Patient registration was slow due to the receiving counter relying on handwritten patient data. This limited the number of patients that could be processed daily, despite the analyzer's high throughput capabilities. Furthermore, all ordered tests were entered manually into each analyzer. The process of manually marking tubes or aliquots with barcodes, as well as transferring samples from tubes to aliquots, increased the risk of identification errors, due to factors such as staff fatigue. Following the completion of tests, patient reports were generated by printing results from each analyzer onto separate sheets of paper. These individual sheets were then attached to create the final report for the patient. These were visually unappealing and difficult to read due to the varying fonts and formats used on different sheets of paper. The results were initially subjected to technical validation by the medical laboratory technologist (MLT), followed by subsequent clinical validation carried out by the medical team in the chemical pathology department under the supervision of the chemical pathologist, who had limited access to previous results which hindered the ability to compare data, potentially impacting the interpretation of the results. The workflow before the implementation of LIS can be observed in Fig. 3.

HIS in use at LRH is an open-source system released under GNU Affero General Public License version 3. This presented a promising opportunity as it meant that the LIS module could be implemented within the HIS framework with further customization by the health informatics team. However, the team encountered challenges related to interfacing the analyzers with the LIS module. The analyzers used in the laboratory required specific software interfaces to communicate and transmit test data to the LIS. Integrating these interfaces with the existing LIS module required coordination with the local agents of the analyzer. In addition to the software challenges, the LIS implementation required additional hardware resources. The hospital needed computers for data entry and result reporting, barcode readers for efficient specimen identification, printers for generating test labels and reports, and tablets for mobile access to the LIS system. To accommodate these hardware requirements, the health informatics team under the supervision of the consultant in health informatics conducted an inventory of the existing hardware infrastructure and assessed the need for upgrades and new acquisitions.

III. Implementation of LIS

The implementation of the LIS at LRH involved the collaborative efforts of experts in the fields of health informatics and chemical pathology. The Hospital Health Information Management System (HHIMS), developed by the Information and Communication Technology Agency (ICTA) in collaboration with the Ministry of Health of Sri Lanka to support various hospital functions was an open-source software that facilitated the implementation of HIS with an LIS module. Traditional software development is time-consuming and expensive, but leveraging existing open-source software offered a significant advantage by reducing both time and cost requirements. Previously, many hospitals in Sri Lanka faced challenges integrating the LIS with the HIS due to the lack of an interface between the laboratory analyzers and the HIS. This lack of connectivity prevented data exchange between the two systems. To address this interfacing issue, the health informatics department worked closely with the local agents of the fully automated analyzer providers. They collaborated on customizing the necessary software interfaces, with the introduction of middleware, a software solution that acts as a bridge between the analyzers and the HIS, so that integration became possible. What made this development even more significant was that the middleware solution was at no cost, making it accessible to hospitals with limited resources. This emphasizes the significance of locally adapted health informatics solutions for cost-cutting, particularly in low-resource settings. Similarly, a government hospital in Malawi during the development of the LIS used custom hardware specifically mobile workstations, used in test ordering by clinicians to minimize cost (Mtonga et al., 2019). The health informatics team procured the required computers, barcode readers, printers, and tablets.

Furthermore, it was ensured that the hospital staff received adequate training on the new hardware and software interfaces. This training included familiarizing staff with using barcode readers for accurate specimen identification, operating printers for generating labels and reports, and utilizing tablets for mobile access to the LIS system. On the other end, medical MLTs and health assistant staff were trained to read barcodes, cross-check the information with the LIS, and validate the generated reports.

IV. Workflow After Implementation of LIS

To begin the testing procedure, the physician uses a unique patient identifier in the form of a barcode, which provides access to the patient's information in the HIS. This unique identifier was assigned upon the patient's arrival at the hospital, following a one-time patient registration process that generates a barcode label which served as a paper-based continuity of care document kept by the patient. When the patient's barcode was scanned, their summary, including past test orders and their status, along with available test results, was displayed at the HIS interface.

The clinician could request new tests using this information. This system additionally maintained track of the tests that the hospital offered, preventing the ordering of unavailable tests. This replaced the traditional paper request forms. After receiving the test order, the HIS created a unique number for the sample, which was printed on a label together with other test order information in both barcode and human-readable formats. The specimen was tracked throughout the whole testing procedure using the unique number, which was manually attached to the specimen tube. Additionally, the system kept track of the time the specimen label was printed, which was used as a timestamp for sample collection thereby fastening the process of specimen reception. Furthermore, the electronic format ensured that all necessary information was accurately recorded, reducing the

risk of errors, and improving the quality of communication between the laboratory and clinicians. The samples were correctly matched with patient information due to the use of barcode labels which reduced the need for manual identification. Upon the specimen's arrival at the laboratory, the laboratory receptionist followed a two-step process. First, they scanned the barcode on the specimen container and simultaneously visually inspected both the container and the test order documentation. Based on this assessment, the receptionist decided whether the specimen should be accepted or rejected. In case of specimen rejection, a notification was sent to the nursing officers through the system, for the recollection of the specimen. If the specimen is deemed acceptable, the laboratory receptionist forwarded the specimen to the MLTs for analysis. One of the key benefits of LIS is the automated order transfer from the system to the laboratory analyzers. This eliminated the need for manual entry of test orders on the analyzers, allowing MLTs to mainly focus on the analytical phase. Once the sample is analyzed the two-way interface between LIS and the analyzers eliminated the need for result re-entry which reduces transcription errors. The results were automatically transmitted to the LIS, where they were made available to the MLTs for technical validation. Subsequently, the medical team clinically validated the results by obtaining information from the clinicians. If necessary, retesting was done using the same sample and if the sample was insufficient, a new specimen was requested through the LIS. The validation interface contained patient demographics and the current test results. Results were highlighted if outside the reference range based on age, sex, and the analyzer if relevant. Previous results of the patient could be accessed through the interface with a simple click of a button. Critical values determined based on the expert opinions of the chemical pathologist and relevant specialists were entered into the LIS and any result falling outside this established range was flagged for further attention. Once the result was verified, it was promptly notified to the clinician through the system. Therefore, LIS could easily monitor the turnaround time, which was the time taken from sample collection to the generation of the final report. The LIS significantly reduced the need for issuing copies of lost reports, reducing cost and saving time for both the laboratory and the clinical team. The workload of the health assistant staff was reduced as there was no need to dispatch results manually. The post-analytical phase was significantly hastened with the implementation of the LIS and the reduction in manual processes. Access to the LIS was limited to authorized staff only, with a unique identification number and password. Furthermore, the LIS maintained a log of all activities performed within the system. Using data from the LIS allows for important operations like establishing reference ranges and conducting scientific studies. The availability of a data repository enabled clinical and laboratory professionals to study trends and run statistical analyses. Fig. 4 highlights the workflow after the implementation of LIS.

V. Impact of LIS on Healthcare Delivery

A. Positive Impacts

- *Reduction in turnaround times for test results* The hospital experienced delays in issuing test results before LIS implementation due to manual data entry. The LIS reduced turnaround times for test results by electronically generating test orders and updating results to the system as soon as they were available.
- *Automation of routine laboratory procedures* The LIS automated routine laboratory processes including tracking samples and reporting results. Due to this, there was less need for manual intervention, reducing human error. The workload of assistant health staff was reduced as manual dispatch of results was not required.
- *Improved report accuracy* Manual data entry errors and transcription errors were decreased with the use of LIS.
- *Integration of LIS with the electronic medical record (EMR)* The hospital's existing EMR system was integrated with the LIS which allowed clinical and laboratory data to be accessed by healthcare professionals from a single platform. The ability to compare laboratory results against previous test results allowed clinicians to provide patient care with a more holistic approach.
- *Real-time data availability for healthcare providers* Real-time data from the LIS made it possible to access patient test results once available, which facilitated clinical decision-making.
- *Improved statistical reports* The laboratory was able to produce statistical reports more quickly and accurately due to the availability of real-time data. This helped in monitoring the efficiency of laboratory operations and resource allocation. Data could also be used for establishing reference ranges and conducting scientific studies.

B. Negative Impacts

- *Increased cost* Implementation and maintenance of the LIS can be costly. The initial investment in hardware, software, and staff training placed a significant financial burden on the hospital's budget.
- *Data Security* Concerns about data security and patient privacy arise when integrating patient data into an electronic system. There is always a risk of potential breaches and unauthorized access to sensitive patient information.
- *Maintenance and Upgrades* Regular maintenance and grades are required for the continuous smooth functioning of a LIS. In low-resource settings, maintaining the system and ensuring timely upgrades may pose logistical challenges.
- *Technical Issues* Like any computer-based system, LIS may experience downtime or encounter technical problems, which could disrupt laboratory operations and result reporting.

In low-income countries like Sri Lanka, the positive impacts of implementing LIS can significantly improve healthcare delivery by optimizing limited resources.

However, these technologies also come with challenges of increased costs associated with the implementation and maintenance of LIS which may strain already limited financial resources in low-income settings, potentially leading to delays in addressing technical issues and keeping technology up-to-date. Long-term sustainability may require support from government, donors, and other stakeholders. In Sub-Saharan African hospitals, limitations in infrastructure and equipment hindered the implementation of quality management systems reflecting the barriers in resource-limited settings to embrace technological advancements (Barbé et al., 2017).

VI. Staff Feedback

Staff satisfaction was evaluated through the use of a Google Form survey, which was distributed among a diverse group of health staff, including consultants, registrars, medical officers, house officers, nurses, medical laboratory technicians, and health assistants (Fig.1). This approach ensured that feedback was gathered from a wide range of individuals representing various roles within the healthcare or laboratory setting. Following the collection of survey responses, the data was analyzed using Microsoft Excel 2019.

Firstly, the survey revealed that all respondents, a notable 98.2%, demonstrated a high degree of readiness to adapt to the new system. A study conducted in a South African hospital revealed challenges in implementing HIS due to clinicians' preference for the traditional paper-based system (Ohuabunwa et al., 2016). Similarly, in a study done in an Iranian hospital, the principal barrier to the implementation of HIS was identified as negative staff attitudes (Ahmadian et al., 2014). Staff resistance to change can be an obstacle during the implementation of a new system, which was not observed in our case. One of the key findings was that 63.6% of respondents acknowledged a reduction in paperwork since the LIS implementation. Additionally, 65.7% of respondents stated they could easily access the results, showing that the LIS had significantly improved the ability to retrieve laboratory data. In addition, 58.2% of respondents stated that the LIS implementation had resulted in faster result reporting. A remarkable 81.6% of respondents claimed that the LIS system has improved their general productivity, leading to improved outcomes and reduced workload for laboratory personnel. Finally, 51% of respondents said the training was sufficient, indicating room for improvement. In a laboratory setting, proper training is essential to ensure that all staff members can use the LIS efficiently. Computer literacy was identified as a mediating factor influencing the satisfaction of health professionals during the implementation of electronic medical records in developing countries (Tilahun & Fritz, 2015), highlighting the importance of computer training for healthcare professionals in these settings.

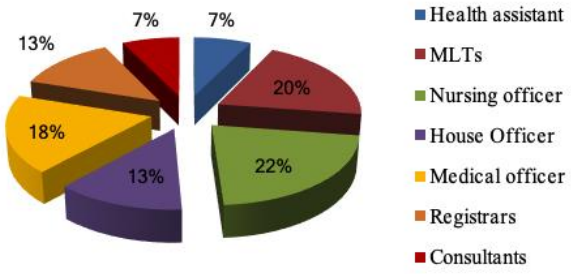

Fig. 1. Distribution of health staff participants in the survey

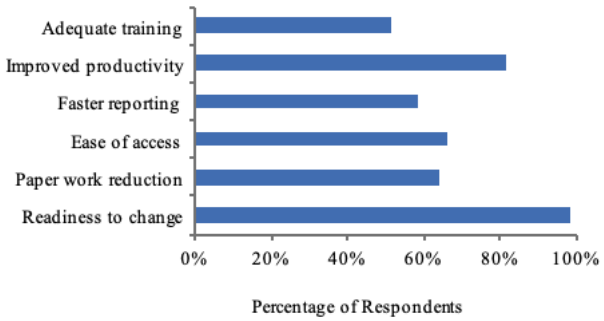

Fig. 2. Results of staff satisfaction survey

VII. Conclusion

This short report highlights the benefits of implementing health informatics interventions to address issues in the laboratory testing process in low-resource settings. The implementation of LIS brings both opportunities and challenges to healthcare delivery. Faster turnaround times, improved data accuracy, electronic storage of data, decreased sample identification errors, and decreased translational errors are some of the advantages. The large amount of data available to chemical pathologists during verification increases the quality of results. Our survey showed a high level of staff readiness to change, with 98.2% stating they were eager to adopt the new system and 81.6 % stating the LIS had increased their productivity, showing a positive impact on day-to-day operations. Although the majority (51%) found the training sufficient, there is space for improvement. Addressing potential negative impacts like high initial expenditure, data security concerns, and adequate staff training is required to ensure effective LIS implementation. Only with the collaboration of the chemical pathology and the health informatics experts can an optimal LIS for specific laboratory requirements be developed. The LIS can be a useful tool to reduce errors in the pre-analytical, analytical, and post-analytical phases by carefully balancing advantages with drawbacks thereby improving healthcare delivery.

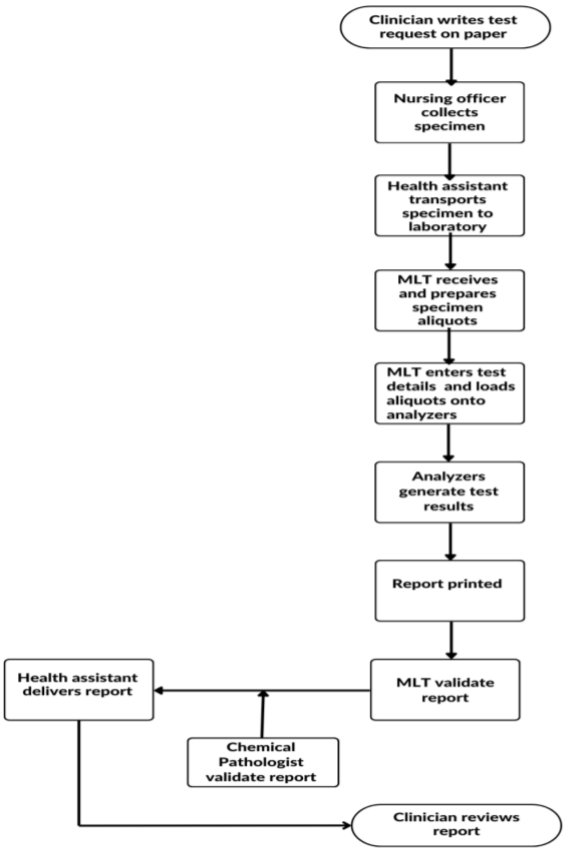

Fig. 3. Workflow before implementation of LIS

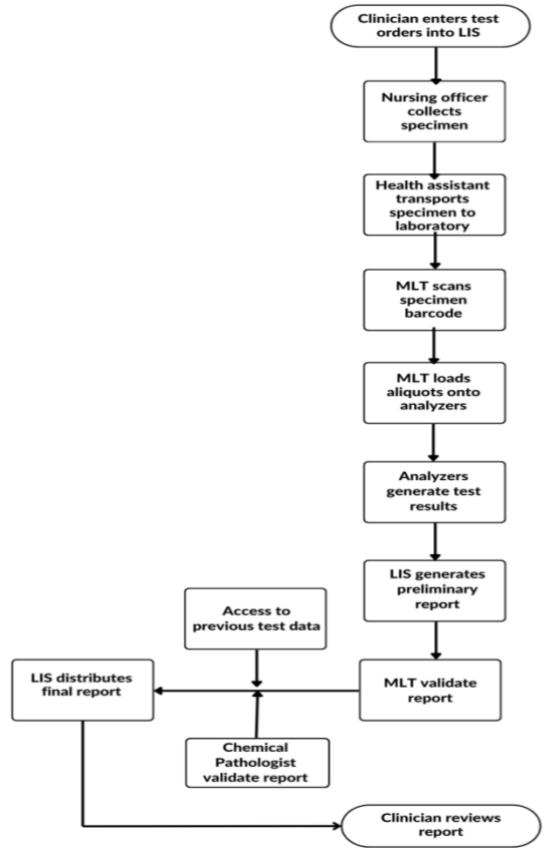

Fig. 4. Workflow after implementation of LIS

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2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

Carbon Footprint Analysis with Simplified Emission Estimation Methodologies

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Abstract*—The global average temperature on July 4, 2023, reached an all-time high of 62.92 degrees Fahrenheit (17.18 degrees Celsius), making it the hottest day on Earth since at least 1979. [1]. This is a great reminder of why people should care about the environment. Being busy with day to today life, people don't have time or motivation to consider their personal carbon footprint. Harder to keep track of daily work and over-complicated carbon footprint calculators cause people to lose track of their carbon emissions. Lack of knowledge about carbon footprints and their impact on the earth's future is another main reason why people don't care about it. Many people believe that climate change is government propaganda, and some believe personal carbon footprint doesn't have an impact on the world since it is very minimal compared to Earth's scale. This research paper proposes a novel approach to calculating carbon footprints using a simple algorithm and interface that eliminates the need for users to remember numerical values. The study presents a methodology to determine personal carbon footprint using predefined values and using simple algorithms to analyze them. The research primarily concentrates on three main components, namely transportation, energy consumption, and food consumption. Each of these components is further subdivided into smaller components to simplify the algorithms. Transportation is categorized into four subcomponents: auto-mobile, aquatic, railway, and aviation. Energy consumption is divided into electricity, gas, and water consumption. Dietary emissions are categorized into food and beverages. Various algorithms will be employed in different subsections, ensuring a loosely coupled structure that enhances accuracy.

Keywords—Carbon Emission, Carbon Footprint, Emission Factor, Layered Architecture

I. INTRODUCTION

Carbon footprint is a metric that measures the amount of greenhouse gases emitted by an individual, organization, or community. It is expressed in metric tons of carbon dioxide equivalent (MT CO2e), which is a measure of the global warming potential of different greenhouse gases [7]. Carbon footprint can be used to track progress in reducing greenhouse gas emissions and to identify areas where emissions can be reduced. However, since this study considers smaller personal carbon emissions other than industrial level kilograms of carbon dioxide (CO2KG) is used as the standard unit [7]. It is important to understand the impact of individual carbon emissions and why it matters. The carbon footprint is an indicator of the amount of greenhouse gases emitted from an activity.

The earth needs warmth for its life to survive. During the daytime, the earth gets its warmth from the sun. While the earth absorbs the heat from the sun up to some extent it reflects most of it. According to the studies that have been carried out, the nighttime should be very cold without the heat from the sun making it very hard for the living species to survive. So, what is stopping the earth from becoming cold at night, the answer is the greenhouse effect. The greenhouse effect is a natural process that occurs in the Earth's atmosphere. This greenhouse gas layer has a significant impact on the earth. It is one of the reasons why the earth is suitable for life. The primary energy source of the earth is the sun. Without it, it is not possible to have life on the earth. but the sun emits different types of harmful solar radiation and heat radiation as well. Greenhouse gases absorb or reflect these unsuitable radiations preventing them from entering the earth. It acts as an invisible filter. Other than filtering the radiation, greenhouse gases act as a cover that traps heat from the sun in the earth's atmosphere preventing the earth from becoming very cold at night. It plays a major role in filtering solar radiation and

maintaining the temperature.

Even though a greenhouse is a very significant and necessary phenomenon increased thickness of this layer can introduce a whole new set of problems. The solar heat cannot escape from the ticker greenhouse layer resulting in increased global temperature. Global warming has its own consequences such as ice melting, rising sea level and coastal floods, extreme weather conditions, disruption of ecosystems, food and water insecurity, health impacts, etc. these problems link one to another, so it is necessary to find the root cause of these issues and find a solution. Climate risks of 0.5-degree change in global temperature are illustrated in figure 1. Even though 0.5 Celsius seems like a very little value it is clear how it affects living species.

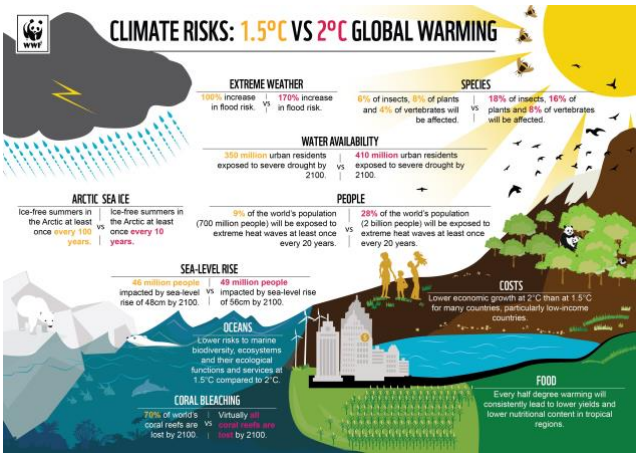

Fig. 1. Climate risks of global warming source: [10]

Being a sub-component of wider research of implementing a technological solution for climate resilience and disaster preparedness, this research component focuses on awaking people about personal carbon emissions and their impact while developing a simple and easier way to calculate personal carbon emissions motivating them to adhere to a low-carbon lifestyle.

II. Literature Review

A. History of Carbon Footprint

The carbon footprint concept is a newer version of the ecological footprint concept, which was developed in the early 1990s by Canadian ecologist William Rees and Swiss-born regional planner Mathis Wackernagel at the University of British Columbia. The carbon footprint concept focuses specifically on the emissions of greenhouse gases, while the ecological footprint concept takes into account a wider range of environmental impacts. [2]

Since the early 20th century, scientists and researchers have been studying how greenhouse gases influenced the Earth's atmosphere. However, it was not until the latter half of the 20th century that the phrase" carbon footprint" became well-known. As concerns over climate change increased and the necessity to measure individual and public carbon emissions became clear, the phrase gained popularity in the early 2000s. The concept was first applied to determine how human activity affected the environment, especially regarding energy usage, transportation, and industrial operations. Governments, corporations, and people began using carbon footprint analysis as a technique to analyze and minimize their contributions to greenhouse gas emissions when climate change became a major worldwide concern. Since then, the carbon footprint has transitioned from a phrase used mainly by scientists and environmentalists to one generally accepted as an essential statistic for analyzing sustainability and encouraging environmentally friendly behavior in a wide range of industries.

B. Problems with Existing Solutions

As climate change becomes a main topic in social media as well as governments and large-scale companies trying to reduce their carbon footprint, a timely solution to educate people and calculate their carbon footprint is necessary. Even though many platforms allow users to keep track of their carbon footprint, there are common missing key features on most of them.

One of the main missing key features can be identified as a lack of guidance. Most existing carbon footprint calculator platforms don't provide users with enough information to help reduce their carbon footprint because they are limited to only calculating carbon emissions. Researchers and developers put so much time and effort into building an accurate carbon footprint calculator, but the results of that process are meaningless if the platform doesn't guide and motivate users to reduce carbon emissions.

Another major flaw of existing carbon footprint calculators can be identified as overly completed calculation processes and not user-friendly designs. Considering the calculations used in existing carbon footprint calculators, it is clear that only simple multiplications, divisions, and additions are used to calculate them. In the standard approach, the users are expected to enter various values, and those inputs are applied to standard equations to get the output. The problem with this approach is that users are expected to memorize the exact numerical values such as liters of petrol burnt. Realistically humans are not naturally programmed to memorize such values, so they have to make an effort to either memorize or note down those values which is not a convenient or user-friendly method to do such tasks.

Although directly depending on the users to enter exact numerical values leads to an accurate result in calculating the carbon footprint it is worth compromising the accuracy to develop an algorithm to predict those values considering the massive positive change it makes on the user experience and convenience. With the advancement of information technology, it is necessary to apply modern technologies to make a positive impact on the planet.

C. Main Objectives of This Research

This research component focuses on those two main goals, educating individuals about climate change and developing a comprehensive solution to replace the existing complicated

carbon footprint calculating process. Combining these two main goals, two in one solution can be introduced as a web or mobile application where users will have the convenience of a modern application and modern technologies such as artificial intelligence, image processing, and deep learning can be used.

III. Methodology

A. Conventional Carbon Footprint Calculation Methods

Several methodologies can be used to calculate the greenhouse gas emission associated with human activities. These techniques include both individual and industrial scales. And consider various factors with different accuracy and complexity levels. The "Emission inventory" method is a common carbon footprint calculation method that can be calculated by collecting data on energy consumption, transportation, industrial activities, and waste management and converting it into CO2 equivalent using emission factors. The emissions factor is a value of how much CO2 will be emitted into the atmosphere by a single unit of its category, for example Burning 1 L of gasoline produces approximately 2.3 kg of CO2 into the atmosphere. The value 2.3 is the emission factor of burning gasoline. Furthermore, the total CO2 emitted canbe calculated using the following equation "(1)". [3]

$$E_x = EF_x \cdot Q \tag{1}$$

- Ex = Emissions of pollutants x
- EFx = Emission factor of pollutant x
- Q = Activity or production rate.

There are several other methods to calculate carbon emission such as the "input-output analysis" method which considers the flow of products and services to estimate their carbon emission throughout the economy. The" life cycle assessment"method considers the entire life cycle of products and services including their production, use, and disposal stages to estimatethe overall carbon emission through their life cycle. The usage of these methods depends on the situation and the scope ofthe calculation process. Each method has its limitations and accuracy levels. So, it is important to have a common ideaof these methods and apply the most suitable method to a particular scenario based on the limitations, and requirements.

B. Challenges with Conventional Approaches

The main methods for determining carbon footprints, from individual to industrial contexts, have been traditional approaches for decades. These traditional methods are still widely used, yet they still have a lot of problems that might make them less useful and effective.

One of the key drawbacks comes from their heavy reliance on numerical values. When the right data is supplied, this can result in great accuracy, but it also presents a challenge because individuals frequently have trouble properly recalling complicated numerical inputs. This makes human mistakes more likely, regardless of how accurate the equation is. The problem, however, mostly is caused by the way that most programs are developed, which strongly relies on user inputs and applies them directly to the equation, eventually reducing user-friendliness. A more relevant strategy would be to streamline data entry while still taking into consideration a wide variety of variables affecting carbon footprints in order to improve these estimations.

C. Design and Development of a Less Numerical Solution

There are several ways to increase the user experience by reducing the exact numerical inputs required by the user. The simplest approach Is to estimate the values without changing the equation itself. As an example, if a user traveled 10 kilometers by car, we could calculate the emission of that commute by multiplying the volume of fuel burned by the emission factor of the fuel type.

Carbon Emission = fuel burned(liter) * emission factor (CO2 per liter)

$$C = V \cdot E \tag{2}$$

- C = CO2 Emission (kg)
- V = Volume of fuel burned (l)
- E = Emission Factor (kgl^{-1})

In this equation, the emission factor is a constant, and the fuel volume is the value that the user should enter to calculate the emission of the commute. Normally the user is required to know the value but practically it's harder to keep track of such variables all the time. Even though there is no need to change the equation it is necessary to find a more user-friendly way to get this value from the user. Instead of directly asking for the value it is more convenient to estimate it even though there will be a compromise in accuracy. Several methods can be used to estimate these values such as questioners chatbots, IoT devices, etc. This research is focused on estimating the variables using a simple guided questionnaire. In this approach, the overall total carbon emission is divided into sub-categories such as transportation energy consumption, food, and industrial to use separate logic to estimate carbon emission. Transportation can be further classified into four main modes: road, rail, air, and sea. This categorization allows for a more optimized analysis of the transportation system itself to get more accurate output.

D. System Architecture

The proposed system will be developed using a three-tier architecture, which separates the presentation layer, application layer, and data layer. This architecture will allow for the system to be developed and maintained more easily, as wellas for it to be more scalable and secure.

The three-tier architecture of the system will consist of a presentation layer, an application layer, and a data layer. The presentation layer will be responsible for interacting with the user and displaying the system's interface. It will be implemented using HTML, CSS, and JavaScript. The application layer will be responsible for processing user requests and interacting with the data layer. It will be implemented using Python. The data layer will be responsible for storing and

retrieving data from a database. It will be implemented using MongoDB.

The system will be developed as a progressive web application (PWA), which will allow users to access it using a variety of devices, including smartphones, tablets, and computers.PWAs are web applications that are installed on the user's device and can be used offline. This makes them ideal for use in environments where there is limited or unreliable internet connectivity.

The system will be developed using the Model-View-Controller (MVC) architectural pattern. This pattern divides the application into three components: the model, the view, and the controller. The model is responsible for storing and managing the application's data. The view is responsible for displaying the data to the user. The controller is responsible for receiving user input and updating the model. This pattern makes the application more modular and easier to maintain. It also offers several other advantages, such as increased scalability, security, portability, and reusability.

Overall, the three-tier architecture and MVC pattern are well-suited for the development of the proposed system. They will allow for the system to be developed and maintained more easily, as well as for it to be more scalable and secure.

E. Algorithm Design and Implementation

The algorithm takes as input the distance traveled, and the vehicle type. It then uses this information to estimate the fuel efficiency of the vehicle, fuel type, the total fuel burnt, and the emission factor. The algorithm can be modified to include other factors that affect fuel efficiency and emission factors, such as road conditions, weather, and driver behavior. The algorithm is a significant improvement over previous methods for calculating carbon emissions from transportation, and it is more reliable, and user-friendly. This algorithm will make it easier for people to calculate their carbon emissions from transportation and make more sustainable transportation choices. the user interaction flow and the sample logic are illustrated in figure 2

F. User Experience

Comparatively higher user satisfaction is expected from this research compared to the conventional approach. The proposed system is expected to provide a number of features that will improve user satisfaction compared to the conventional approach. These features include:

- A question-based user interface (UI) that is easy to use and understand.
- The ability to generate reports and see real-time statistics of carbon emissions over time.
- Personalized carbon reduction guidelines based on user results.

The question-based UI is expected to be more user-friendly than the conventional approach, which often requires users to input complex data. The question-based UI will allow users to simply answer a series of questions about their lifestyle and habits, and the system will automatically calculate their carbon footprint.

The ability to generate reports and see real-time statistics of carbon emissions over time is expected to be a valuable feature for users who want to track their progress and make informed decisions about reducing their carbon footprint. The reports will provide users with a detailed breakdown of their emissions, and the real-time statistics will allow users to see how their emissions change over time. The dashboard UI is illustrated in Figure 3.

The personalized carbon reduction guidelines are expected to be a helpful tool for users who want to make changes to their lifestyle in order to reduce their carbon footprint. The guidelines will be tailored to each user's individual needs and circumstances, and they will provide users with specific suggestions for how they can reduce their emissions.

Overall, the proposed system is expected to provide a number of features that will improve user satisfaction compared to the conventional approach. These features are expected to make the system more user-friendly, informative, and helpful for users who are interested in reducing their carbon footprint.

G. User Interaction Flow

The carbon emissions calculator component is part of a larger research project that aims to provide an all-in-one solution for climate resilience and disaster preparedness. The calculator can be accessed from the home page or navigation bar.

The first user interface (UI) that users interact with is the dashboard, which is illustrated in Figure 3. The dashboard provides users with a summary of their carbon emissions, as well as tips and tricks on how to reduce them. Users can also choose to calculate their carbon emissions or visit the tips and tricks page from the dashboard.

When users choose to calculate their carbon emissions, they are first asked to choose one of three methods: quick, average, or advanced. Each method considers different areas of a user's lifestyle and takes a different amount of time to complete. A comparison of the three methods is given in Table I.

TABLE I
COMPARISON OF CARBON EMISSIONS CALCULATOR METHODS

Method	**Area considered**	**Estimated time to complete**
Quick	Transportation, energy consumption	5 minutes
Average	Transportation, energy consumption, diet	10 minutes
Advanced	Transportation, energy consumption, diet, travel, waste, lifestyle choices	30 minutes

After choosing a method, users are asked to answer a series of questions about their lifestyle and habits. The system then uses the answers to these questions to calculate the user's carbon emissions. The results are displayed in a user-friendly format that allows users to see where their emissions are coming from and how they can reduce them.

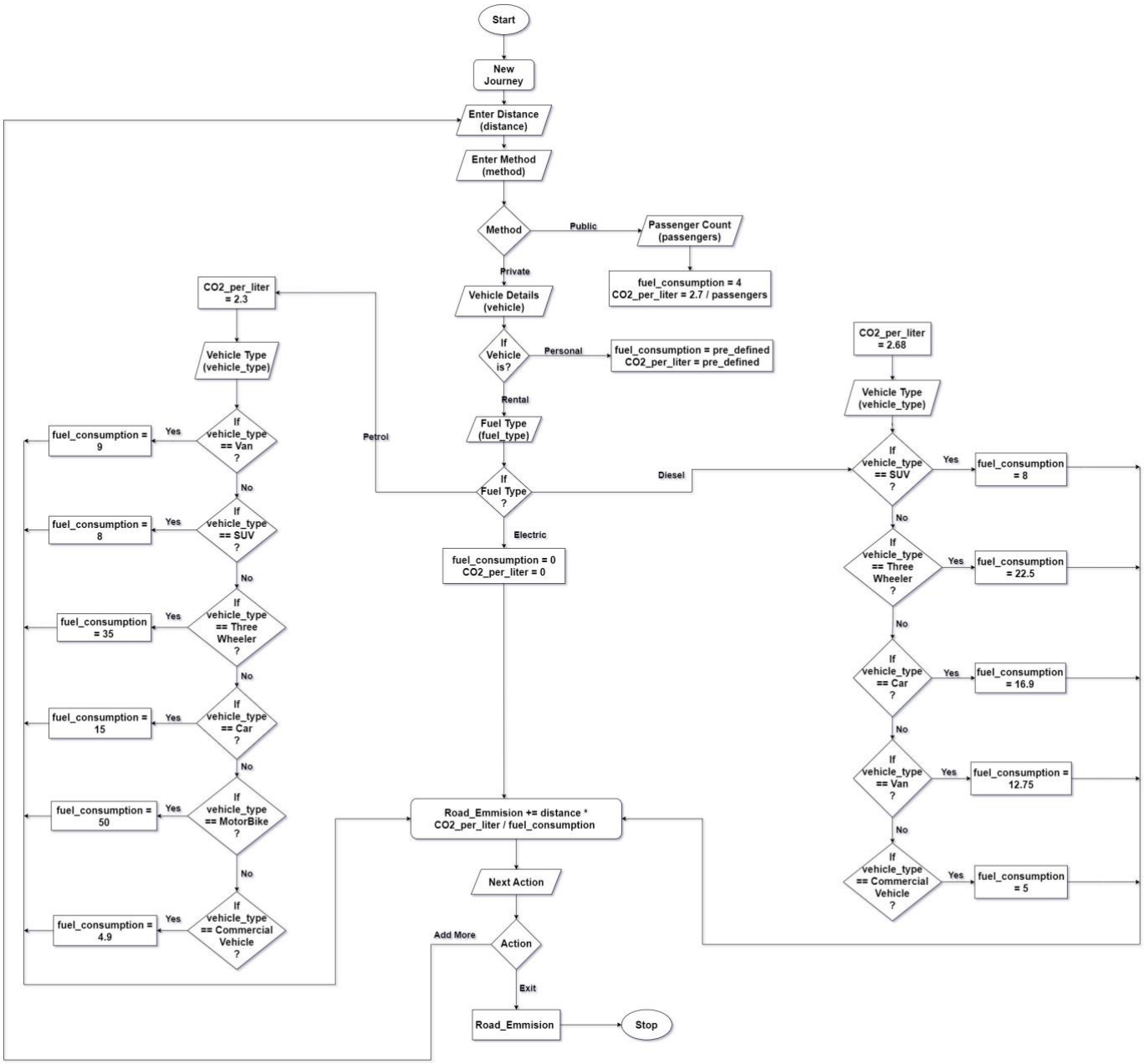

Fig. 2. Estimation logic

IV. Results and Discussions

A. Comparison with Conventional Methods

The proposed algorithm is a good compromise between accuracy and convenience. It is more accurate than previous methods that require users to know the fuel efficiency of their vehicle. However, it is not as accurate as the conventional method, which requires users to manually enter the fuel efficiency. The proposed algorithm is more convenient and user-friendly, which will lead to more people using it and therefore more accurate estimates of carbon emissions overall.

The slight loss of accuracy is manageable because carbon footprint calculation is not a critical calculation. Carbon footprint is not used to make decisions that could have life-or-death consequences. Therefore, a slight error in carbon footprint calculation is not a major concern.

a comparison between known value and estimation is illustrated below.

Actual Value (Known Values):

- Vehicle Type = Car
- Fuel Type = Petrol
- Distance = 10 km
- Fuel Consumption = 12 kmpl
- Emission Factor of Petrol = 2.3 CO_2 per Liter
- Emission (Actual) = 1.91 CO_2

Estimation:

- Vehicle Type = Car (Selection)
- Fuel Type = Petrol (Selection)
- Distance = 10 km (Input)
- Fuel Consumption = 15 kmpl (Estimation)
- Emission Factor of Petrol = 2.3 CO_2 per Liter (Estimation)
- Emission (Estimated) = 1.53 CO_2

$$\text{Accuracy} = (1.53 / 1.91)\ \% = 80\%$$

B. Limitations and Future Directions

Trending technologies like IoT and machine learning can significantly boost the precision of carbon emission calculations. IoT sensors capture real-time vehicle data, allowing ma- chine learning algorithms to predict emissions and offer personalized guidance. For example, the algorithm might suggest a more efficient route if it anticipates a user running late for work. GPS location data helps accurately calculate commutes, minimizing emissions by recommending less congested routes. These enhancements extend to areas like diet, energy consumption, and waste management. IoT sensors monitor food and energy usage, with machine learning identifying patterns for emission reduction. The algorithm may highlight high- carbon-footprint foods and propose eco-friendly alternatives. Similarly, for energy-intensive appliances, it suggests more efficient usage. Refining carbon emission calculations through IoT and machine learning empowers individuals to make informed lifestyle decisions, reducing their carbon footprint. Future research can explore advanced concepts for further enhancement.

V. Conclusion

This research paper addresses the challenge of calculating individual carbon footprints through a user-friendly algorithm that eliminates the need for precise numerical inputs. In the context of escalating environmental concerns, the proposed solution prioritizes user experience by offering a streamlined, question-based interface, real-time statistics, and personalized reduction guidelines. The research emphasizes the importance of understanding carbon emissions' impact on climate change and the need for accessible tools to motivate sustainable lifestyle choices. While the proposed method may entail a slight compromise in accuracy, its convenience is expected to foster greater user engagement and behavior change. The paper also suggests the future integration of emerging technologies like IoT and machine learning to enhance accuracy and broaden the scope of carbon reduction efforts. In sum, this research contributes to encouraging a low-carbon lifestyle by combining technology, user experience, and environmental awareness.

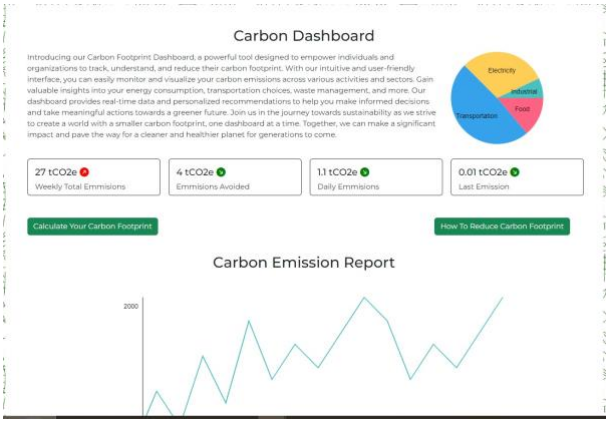

Fig. 3. Carbon emission dashboard

Acknowledgment

The researchers extend heartfelt appreciation to Dr. Samantha Rajapaksha, their esteemed project supervisor, for in- valuable guidance and motivation. Ms. Jenny Krishara, the co-supervisor, receives thanks for crucial insights during the research planning phase. The CDAP panel's guidance significantly shaped the project. A special thanks goes to research project leader Peiris W.O.A and fellow group members for their contributions. This collective effort led to the successful completion of the research. The researchers express gratitude to all, acknowledging the collaborative spirit and shared commitment that enriched the overall experience.

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2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

BER Analysis in PS-SLIPT Architecture Using Different Modulation Schemes

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***Abstract*—Simultaneous Lightwave Information and Power Transfer (SLIPT) has emerged as a highly popular area of research in recent times. The basic idea behind SLIPT is to use light waves to simultaneously transfer power and transmit information. This could lead to significant improvements in the efficiency and sustainability of wireless power transfer systems and enable the development of novel applications such as wireless optical communication. In this paper, we presented the On-OFF Keying (OOK), Quadrature Phase Shift Keying (QPSK) and 8- Phase Shift Keying (8-PSK) constellation diagrams in the Power-Splitting SLIPT (PS-SLIPT) system. In addition, we expanded the work to BER analysis in the PS-SLIPT system with OOK, QPSK and 8-PSK modulation schemes.**

Keywords—PS-SLIPT, OOK, QPSK, Bit Error Rate (BER)

I. INTRODUCTION

In the latest version of SLIPT, Energy Harvesting (EH) has been incorporated alongside the traditional use of illumination and communication. The system, as proposed in [1], splits the received photon current into two components: Alternative Current (AC) and DC, which are used for ID and EH, respectively. The DC component, which is separated from the AC, is stored in the battery to provide backup power, while the remaining power is utilized for information detection [2-5]. Given its ability to convert optical signals into electrical signals, the use of solar cells is a dependable choice for developing the SLIPT receiver. The SLIPT system model is a subset of Visible Light Communication (VLC) [6]. There are a few reasons to over from analog modulation to digital modulation in wireless communication such as spectral efficiency, power efficiency, the robustness of channel impairment and the low-cost implementation. Digital modulation is transferring a digital bit stream over an analog channel at a high frequency. Moreover, digital communication schemes contribute to the evolution of wireless optical communication by increasing capacity, speed and quality.

The PS receiver splits the incoming signal into two separate power streams, both of which are transmitted to an information decoder and an energy harvester, thereby enabling simultaneous ID and EH. The conventional communication system's power-splitting design need not be modified, except for the receiver circuit. The PS ratio in each receiver can be optimized, and by adjusting these ratios, the information rate and harvested energy can be balanced to meet the system's requirements. Improving overall performance is also possible by optimizing the combination of the signal and PS ratios. The power-splitting coefficient value for EH is denoted by ρ, while $(1-\rho)$ is used for the ID, as described in [7]. The VLC technology relies on Intensity Modulation and Direct Detection (IM/DD) to transmit data. This is achieved by varying the intensity of the LED and modulating the information signal. IM is always non-negative. Two carrier modulation schemes are available: single-carrier and multi-carrier. The former includes modulation techniques such as On-Off Keying (OOK), Pulse Amplitude Modulation (PAM), and Pulse Position Modulation (PPM), Phase Shift Keying (PSK), while the latter includes Orthogonal Frequency Differential Modulation (OFDM), as stated in [8].

A. Contributions

The main contributions of this work are listed as follows:

- Identified the different modulation schemes for PS-SLIPT architecture.
- Explained the behaviour of the constellation diagram using MATLAB simulation in the PS-SLIPT system.
- Described the BER analysis using OOK, QPSK and 8-PSK modulation schemes in the PS-SLIPT system.

B. Paper Organization

The remainder of the paper is organized as follows: Section II presents the system model of the PS-SLIPT communication system. Section III, results and discussion and V conclude the whole paperwork.

II. SYSTEM MODEL

In this section, we discuss the basic system model of SLIPT. Fig. 1. shows the basic system model of the VLC and considers LoS between the Transmitter (Tx) and the Receiver (Rx). This system model uses a wireless communication channel, and it is free space. Also, free space is a medium between Tx and Rx and it has high bandwidth and does not require a licence for visible spectrum. The α denotes the FoV of the LED, θ denotes the Photodiode (PD) and d is the distance between Tx and Rx.

Fig. 2. (a) shows the overall system model of the SLIPT system. It shows the variation of one domain to another domain. There are three parts of the system, namely the

transmitter, channel and receiver. The transmitter includes an information signal, modulator, and converter circuit of electrical signal into an optical signal and LED. The information signal is transmitted as binary data ($m(t)$) and used the modulation techniques to modulate the signal ($m'(t)$) to send the E to the L driver circuit. Here, (t) denotes sequence of binary data. On-Off Keying (OOK) modulation technique is generally used for VLC communication. Using the drive circuit, convert the electrical signal into an optical signal. Also, LED helps to send the optical signal to the receiver. Moreover, h is the channel gain coefficient between the transmitter and the receiver with AWGN. The AWGN ($n(t)$) is a basic noise model used for information theory to follow the effect of the many random processes that occur in nature in wireless communication. The receiver includes PD or solar cells, the converter circuit, demodulation, and the output data. The PD or solar cell detects the optical signal and sends it to the L to the E driver circuit. Using the drive circuit, convert an optical signal into an electrical signal and used demodulation to output data. Figure 2: (b) shows the PS-SLIPT receiver architecture. On the receiving side, there are two functions EH and ID. Further, the received signal is divided into two portions: the AC component and the DC component. The modulated signal gives an AC component and its support to transmit the information. Also, the DC component helps with energy harvesting. The ρ is the power splitting coefficient.

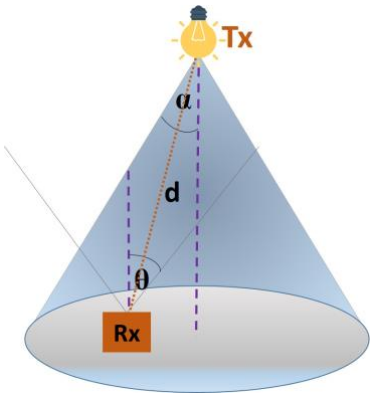
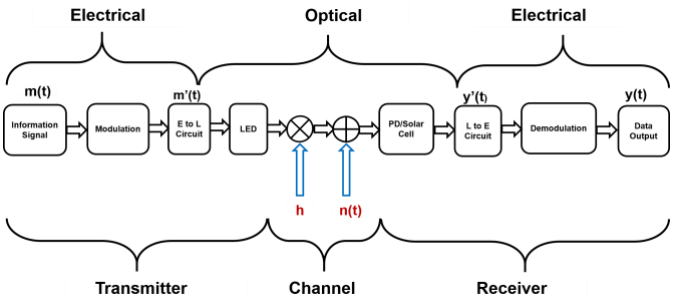
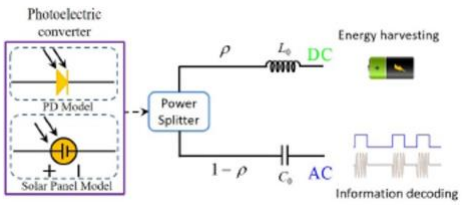


Fig. 1. Basic system model of the VLC and LoS between the Transmitter (Tx) and the Receiver (Rx)



(a)



(b)

Fig. 2. (a) Block diagram of the overall system model of the VLC. (b) PS-SLIPT receiver architecture.

$$h = \frac{A_r(m+1)(cos^m(\alpha)T(\theta)g(\theta)(cos(\theta)}{2(\pi)(d^2)}, \quad 0 \le \alpha \le \pi, \quad 0 \le \theta \le \pi,$$

h is the channel gain between the Tx and Rx [1].

Where d is the distance between the transmitter and the receiver, $T(\theta)$ defines the optical filter gain and Ar denotes as the physical area of the detector at the receiver end. The α denotes the FoV ($0 < \alpha < \pi$) and it is representing as the angle of irradiance of LED. The θ denotes the FoV ($0 < \theta < \pi$) and it is representing as the angle of incidence of LED.

$$m = \frac{-ln(2)}{ln(cos(\alpha))}, \qquad 0 < \alpha < \pi,$$

Where, m denotes the Lambertian's mode number, and it gives the direction of the source. Gain of the optical concentrator is given [1].

$$g(\theta) = \frac{n^2}{sin^2(\theta)}, \qquad 0 < \theta < \pi,$$

n denoted as the refractive index and $g(\theta)$ assign the optical concentrator gain.

The AC component of the signal use for the information decoding process. Signal to Noise Ratio (SNR) for PS SLIPT system denoted by [1],

$$\gamma_{PS} = \frac{(\eta h(1-\rho)P_{LED}A)^2}{\sigma^2},$$

Where the amplitude of the transmitted signal denotes A and **ρ** is the PS coefficient. $\boldsymbol{\sigma^2}$ denotes the noise power (thermal noise and shot noise).

III. Results and Discussion

In this chapter, we present the simulation results of the proposed system models of the SLIPT architectures. Further, present the simulation results of BER for different modulation schemes such as OOK, QPSK and 8-PSK in PS SLIPT architecture.

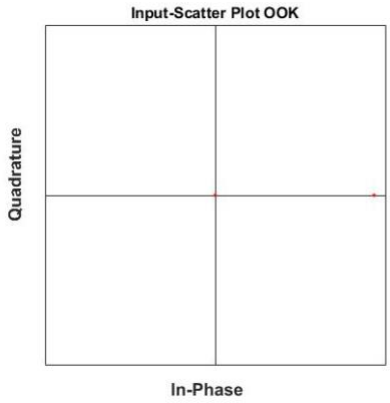


Fig. 3. Input constellation diagram of OOK

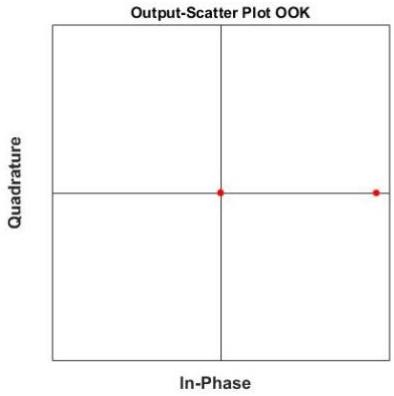


Fig. 4. Output constellation diagram of OOK

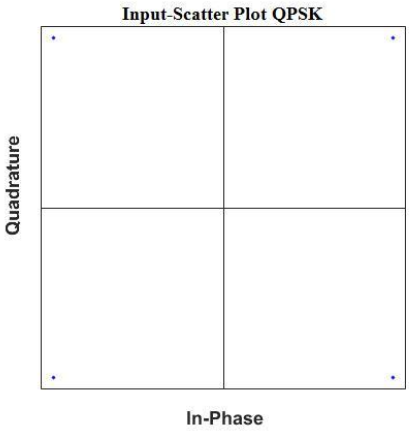


Fig. 5. Input constellation diagram of QPSK

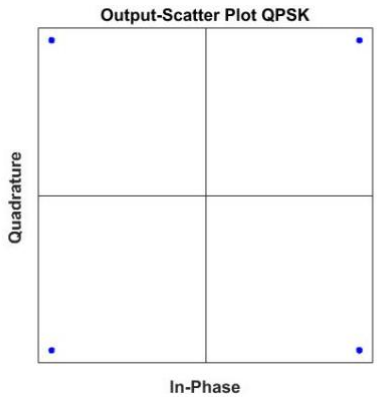


Fig. 6. Output constellation diagram of QPSK

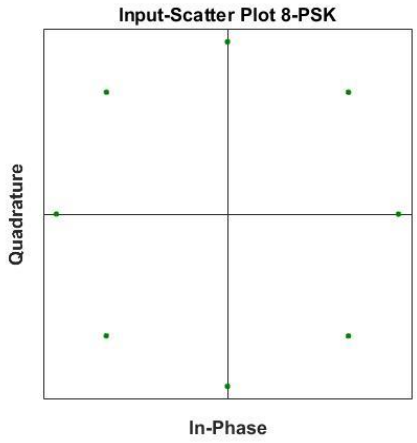


Fig. 7. Input constellation diagram of 8-PSK

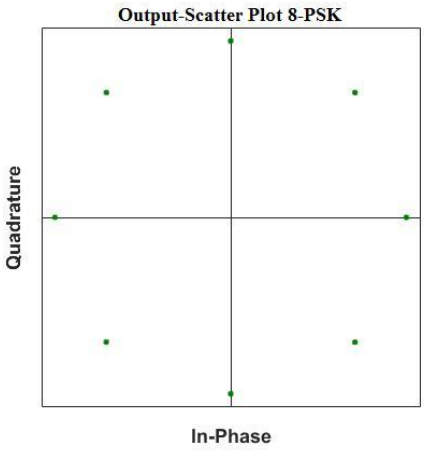
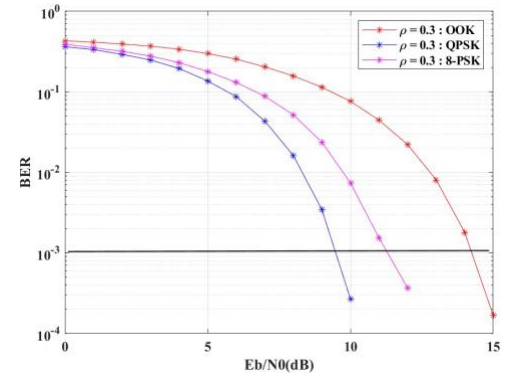
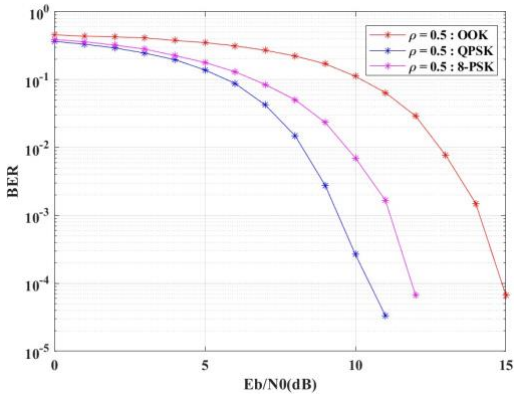


Fig. 8. Output constellation diagram of 8-PSK

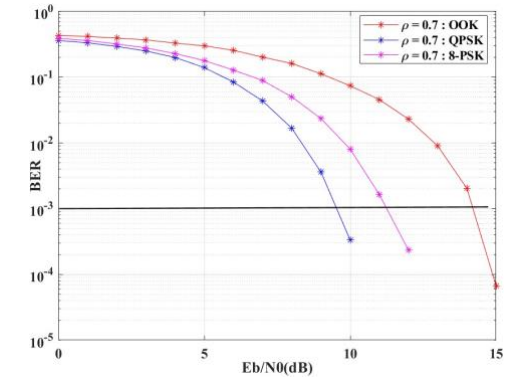
Fig. 3. and Fig. 4. shows the input and output constellation diagram of the OOK modulation, Fig. 5. and Fig. 6. show the input and output constellation diagram of the QPSK modulation, Fig. 7. and Fig. 8. show the input and output constellation diagram of the 8-PSK and represent the effect of noises to the received signals at SNR is 30 dB at ρ=0.7. The OOK is the amplitude modulation scheme commonly used in optical communication applications and it is a lower-order modulation scheme. Further, we use two higher-order modulation schemes such as QPSK and 8-PSK. Both higher-order modulations are phase modulations. The M-PSK modulations are used for this system to enhance the bandwidth efficiency and advantage is by using smaller phase shift, more bits can be transmitted per symbol. This system uses AWGN noise and compared the input and output constellation of each modulation scheme. The constellation diagrams represent symbols in digital modulation schemes. Using visual inspection of constellation diagrams can help diagnose various types of signal impairments. The constellation diagrams show the difference between input and output points. In this system, errors are caused by the transmitter and channel noise. The output point is spread out over the input due to adding the noise and the spurious signal level.



(a)



(b)



(c)

Fig. 9. BER vs SNR of the OOK, QPSK and 8-PSK modulation schemes at (a) ρ = 0.3, (b) ρ = 0.5, and (c) ρ = 0.3.

Fig. 9. (a) shows the BER vs SNR of the OOK modulation scheme, Fig. 9. (b) shows the BER vs SNR of the QPSK modulation scheme and Fig. 9. (c) shows the BER vs SNR of the 8-PSK modulation scheme. It considers the different power splitting factors (ρ) such as 0.7, 0.5 and 0.3. The QPSK shows outperform the 8-PSK and OOK. The QPSK can transmit 2 bits per second and M=4. The 8-PSK can transmit 3 bits per second and M=8. When comparing the QPSK and 8-PSK, 8 PSK is more susceptible to noise as the symbols get closer together. Therefore, QPSK outperforms 8-PSK. Moreover, OOK shows the worst performance due to OOK being susceptible to noise as the bits get closer together than QPSK and 8-PSK.

IV. Conclusion

In this paper, BER analysis in PS-SLIPT architecture using different modulation schemes such as OOK, QPSK and 8-PSK. We observed the input and output constellation diagram of the PS-SLIPT system. In addition, we analyzed the BER of the PS-SLIPT architecture in OOK, QPSK and 8-PSK to identify the most suitable modulation scheme for PS-SLIPT communication scheme.

Acknowledgement

This work was supported by the Fundação para a Ciência e a Tecnologia, Portugal as part the Project Ref[a] 2022. 03897. PTDC

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2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

Predictive Modeling for Identifying Insomnia Risk Factors: An Investigative Approach

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Abstract*—Global populations are significantly impacted by insomnia, a prevalent sleep problem that negatively impacts daily functioning and general well-being. The intricacies of insomnia are explored in this study by utilizing a large dataset that includes both self-reported tests and thorough questionnaires covering various topics, including sleep habits, stress levels, early life events, and cognitive impairments. The study's main objectives are finding relevant components, examining correlations, and utilizing predictive modeling approaches to reveal important insights. We used advanced feature selection techniques to understand the complex interactions between variables. This study examined the intricacies of insomnia's effects on adolescents utilizing a range of statistical metrics, including correlation coefficients and *p*-values. *P*-values, which show how significant the observed links are, and correlation coefficients, which show how strong and which way the relationships are going, are important metrics in our analysis. Using a variety of machine learning methods, such as Decision Trees (DT), k-Nearest Neighbors (k-NN), Support Vector Machines (SVM), and Naive Bayes (NB), one of the study's main goals was to predict insomnia-related outcomes. Among the models evaluated, the Decision Tree classifier was the most accurate, with an exceptional accuracy rate of 89.47% for both feature selection strategies. These results highlight how reliable Decision Trees are at identifying patterns of sleeplessness. Additionally, the investigation found statistically significant correlations between particular demographic characteristics and insomnia. An important positive link between sex and insomnia was found, with a correlation coefficient of 0.078 and a *p*-value of 0.001. Age and insomnia showed a significant positive link (correlation coefficient = 0.250). However, the *p*-value of 0.553 suggests that more research is needed to understand this relationship fully. Further supporting the need to consider these factors for a thorough understanding and management of insomnia, the study found significant correlations between race (correlation coefficient = 0.05, *p*-value = 0.0) and ethnicity (correlation coefficient = 0.179, *p*-value = 0.716) with insomnia.

Keywords—Insomnia, machine learning, predictive modeling, sleep disorders, sleep patterns

I. INTRODUCTION

An extensive public health concern with far-reaching effects on populations worldwide is insomnia, a common and complex sleep disorder. The detrimental impacts on people's daily functioning and well-being highlight the importance of thoroughly understanding the issue and implementing appropriate management techniques. Many unpleasant symptoms, such as persistently low energy, impaired concentration, irregular appetite, and unsettling mood swings, are commonly experienced by insomniacs. These expressions severely impair people's capacity to function at work and carry out daily tasks, setting off personal and professional difficulties.

The division of insomnia into discrete subtypes, specifically Acute, Chronic, and Comorbid Insomnia, facilitates a sophisticated understanding of the disorder's diverse manifestations and underlying complexity. Acute insomnia is a condition marked by brief episodes of disturbed sleep, usually brought on by acute stressors or environmental changes. It frequently goes away without the need for ongoing medical care. On the other hand, long-lasting chronic insomnia requires specialized and all-encompassing treatment strategies that address the various factors that contribute to its persistence, such as physiological, psychological, and environmental aspects. Comorbid Insomnia highlights the complex interaction between sleep disorders and more general health issues when it coexists with other medical or psychiatric conditions. This highlights the value of integrated care models that address the underlying illness and related sleep disturbances [1, 2]. Fig. 1 depicts the insomnia variation with age in 2022.

The startlingly high incidence of severe insomnia, which impacts roughly 10% of the world's population, highlights the need to give robust and comprehensive sleep health initiatives top priority on both the individual and societal levels. Significantly, the complex relationships that exist between insomnia and several serious health issues, including diabetes, heart disease, obesity, and depression, underscore the complex reciprocal relationship that exists between the quality of one's sleep and one's general health. The need to implement efficient preventive and management strategies is increased due to the interconnectedness of healthcare systems, which strains them and increases the burden on individuals [3].

A comprehensive and holistic approach is necessary to address the multifaceted issues associated with insomnia. This approach should incorporate lifestyle modifications, cognitive and behavioral therapies, tailored therapeutic interventions, and more significant public health initiatives. Stress reduction methods, sleep hygiene education, and encouraging good sleep habits should all be prioritized to significantly reduce insomnia's prevalence and the health hazards that come with it. Furthermore, developing a deeper comprehension of the complex relationships between sleep, mental health, and physical health is essential to developing long-lasting public health policies promoting early detection and intervention techniques. Fig. 2 shows the variation in US adult's experience of insomnia in 2022.

A. *Background and Significance*

Because of the complex interplay of factors such as circadian rhythms, pubertal development, academic pressures, social demands, reduced parental oversight, and excessive use of digital media, adolescents are especially vulnerable to sleep problems. This vulnerable group frequently struggles with sleep deprivation, irregular sleep patterns, and daytime sleepiness (DS). Furthermore, adolescents often face emotional and social challenges, with a significant proportion experiencing depression symptoms. According to studies, one-third of adolescents experience depressive symptoms, and 20% experience major depressive disorder during their lifetime [4]. The presence of insomnia, DS, and depression not only impairs daily functioning but also raises the risk of substance abuse, accidents, and suicidal ideation.

B. *Insomnia as a Global Health Concern*

Machine Learning (ML) appears to be a promising tool for comprehending and treating the complexities of insomnia. Supervised learning in ML allows algorithms to detect patterns in large datasets and classify outcomes based on pre-labeled variables [5]. This study uses data-driven analysis to identify the underlying factors contributing to insomnia. The study aims to extract actionable insights by delving into specialized insomnia datasets. This investigation seeks to bridge the gap between data-driven analysis and practical solutions for people dealing with insomnia. We hope this research will provide hope and tangible support to those suffering from insomnia, improving their overall well-being and quality of life.

C. *Objectives of the Study*

This research is based on analyzing the dataset based on insomnia, which will aim to understand this disorder and improve the well-being of affected individuals. While identifying the contributing factors such as sleep patterns, personality traits, cognitive processes, stressors, coping mechanisms, and childhood experiences. Using statistical analyses to explore patterns and correlations within the dataset and identify relationships between different variables can provide valuable insights into the interplay of various factors contributing to insomnia. Using ML algorithms and statistical modeling techniques to develop predictive models for insomnia, predict the likelihood of insomnia occurrence based on specific variables, enabling early identification and intervention for at-risk individuals.

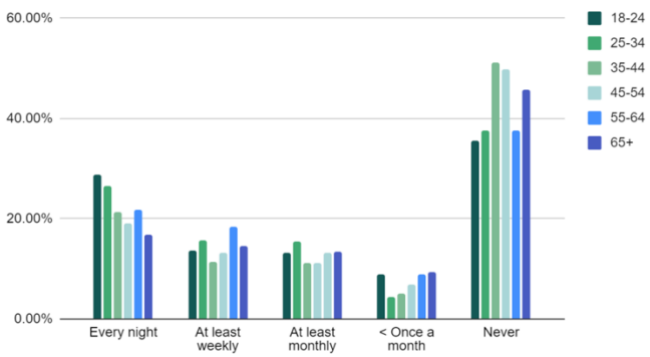

Fig. 1. Frequency of insomnia by age group in 2022, *Adopted from [2]*

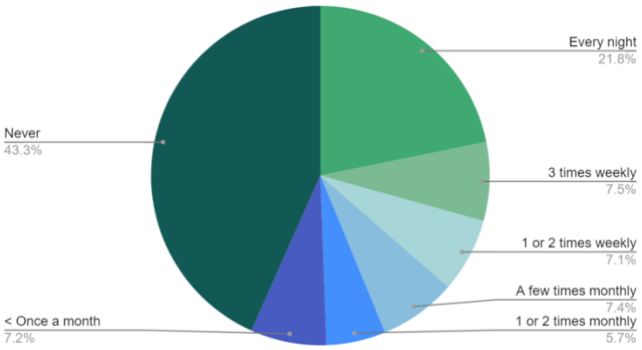

Fig. 2. Occurrence of insomnia among adults in the United States in the year 2022, *Adopted from [2]*

II. Literature Review

The focus of research attention has shifted recently to insomnia, a common sleep disorder, leading researchers to use a variety of approaches, most notably the use of machine learning algorithms. This method has produced insightful findings that clarify the frequency, consequences, and underlying risk factors associated with insomnia. These studies advance our understanding of this disorder and pave the way for novel risk assessment and predictive modeling approaches.

Research findings consistently emphasize the widespread occurrence of insomnia among diverse demographics. A study by researchers [1] delved into the utilization of multiple machine learning algorithms to forecast patterns of insomnia, contributing valuable insights to the expanding literature on insomnia prediction. The use of predictive modeling has dramatically improved the field of health research. Liu et al. [4] conducted a longitudinal study to investigate the relationship between daytime sleepiness, depression symptoms, and insomnia in teenagers. They used predictive modeling techniques to provide crucial new information about the complex relationships between these variables. Their study emphasizes the critical importance of holistic assessments in understanding the varied effects of insomnia and the demand for a thorough comprehension of the complicated dynamics at work. Additionally, Kim's research [5] underscores the changing landscape of insomnia-related technologies, emphasizing the transformative capabilities of artificial intelligence (AI) and machine learning.

Singareddy et al. [6] investigated the relationships between several variables and the emergence of chronic insomnia, including behavioral characteristics, psychiatric and medical disorders, demographics, and polysomnography. The study addressed the shortcomings of earlier research by performing a prospective analysis on a large general population sample over an extended follow-up period. The study used information from the Penn State Sleep Cohort, which included 1395 participants who were followed up after 7.5 years and 1741 adult participants. Those who did not have chronic insomnia at the start of the study (n = 1246) were included. Sleep history was collected at both the baseline and follow-up visits, and baseline assessments included extensive medical and psychiatric histories, personality tests, and an 8-hour polysomnography.

The goal of Inouye et al. [7] was to create and validate a predictive model based on admission characteristics that would anticipate the occurrence of new cases of delirium in

hospitalized elderly medical patients. The study comprised two concurrent prospective cohort studies that were carried out in a university teaching hospital. Among the risk factors that were found, delirium was independently predicted by vision impairment, severe illness, cognitive impairment, and a high blood urea nitrogen/creatinine ratio. A risk stratification system based on these factors successfully identified patients at different risk levels.

In their study of the epidemiology of insomnia, Taylor et al. [8] emphasized the condition's role as a risk factor for several illnesses, with a focus on its predictive relationship to substance abuse, psychological disorders, anxiety disorders, depression, and suicidal thoughts. In addition, sleeplessness was associated with immune system dysfunction, but there was conflicting data about its role in cardiovascular disease and death. On the other hand, it was discovered that the usage of sleeping pills predicted death. Notably, the review noted several shortcomings in the examined studies, such as inadequate control for competing theories and poorly defined criteria for insomnia. Notwithstanding these limitations, the review emphasized the importance of insomnia as a risk factor for deteriorated mental and physical health.

The interdisciplinary nature of studies on insomnia was demonstrated by researchers in [2], who focused on using machine learning techniques to identify potential risk factors associated with insomnia. Huang's work reflects the coming together of technological progress and clinical understanding to produce complex insights into the difficult terrain of insomnia risk factors. Furthermore, Kiss et al.'s extensive dataset [9] provides a complex viewpoint on the symptomatology of teenage insomnia. This dataset, which comes from standardized questionnaires, is helpful for scholars who want to learn more about the complex relationship between insomnia and adolescent mental health. Tab. 1 depicts the summary of the related studies.

TABLE I. SUMMARY OF RELATED WORKS ON INSOMNIA AND INSOMNIA-RELATED MACHINE LEARNING STUDIES

Study	Summary
[1]	They utilized multiple machine learning algorithms to forecast patterns of insomnia, contributing valuable insights to the literature on insomnia prediction.
[3]	They conducted a longitudinal study investigating the relationships between daytime sleepiness, depression symptoms, and insomnia in teenagers, emphasizing holistic assessments for understanding the complex dynamics.
[4]	They highlighted the transformative potential of AI and machine learning in insomnia-related technologies.
[5]	They explored relationships between various factors and chronic insomnia, utilizing a large general population sample and addressing prior research limitations.
[6]	They developed and validated a predictive model for new cases of delirium in elderly medical patients, identifying key risk factors, including vision impairment and cognitive impairment.
[7]	They underscored insomnia's role as a risk factor for various illnesses, particularly highlighting its predictive connections to substance abuse, psychological disorders, anxiety, depression, and suicidal ideation.
[2]	They utilized machine learning techniques to identify potential risk factors associated with insomnia, showcasing an interdisciplinary approach.
[8]	They provided a comprehensive dataset offering insights into teenage insomnia symptomatology, serving as a valuable resource for understanding the complex relationship between insomnia and adolescent mental health.

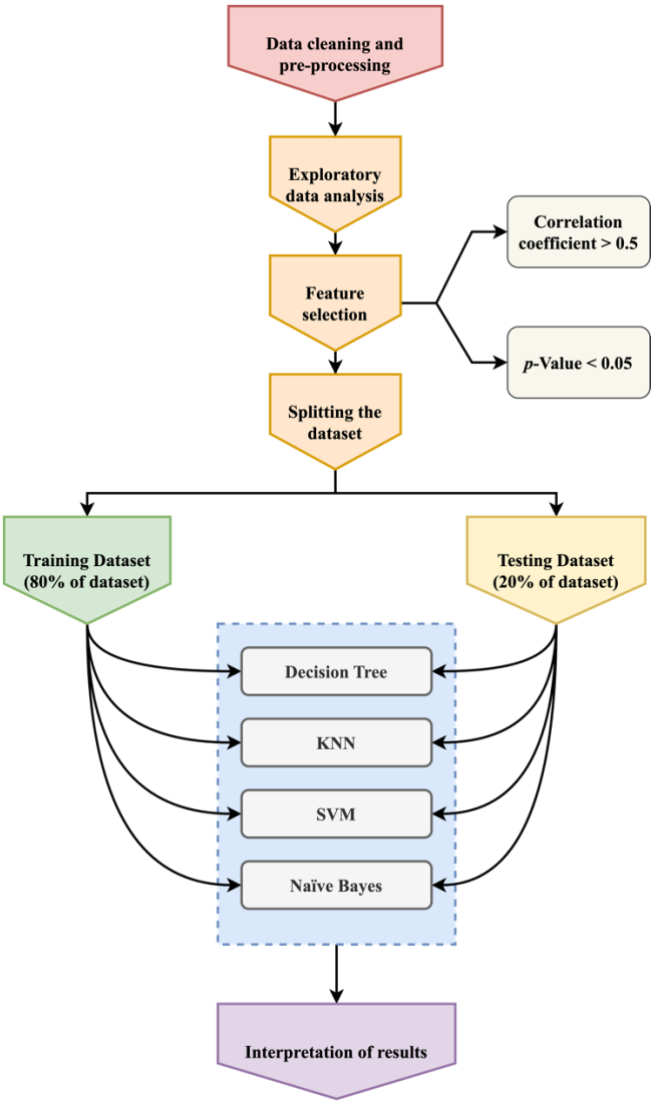

Fig. 3. Model development methodology

III. PREDICTIVE MODEL DEVELOPMENT FOR INSOMNIA RISK ASSESSMENT

In this section, the study's proposed methodology is presented. As depicted in Fig. 3, the model development methodology, aiming to forecast insomnia, is outlined. Preceding the feature selection, the process entails data cleaning and preprocessing.

A. Data Collection and Preprocessing

The dataset used in this study consists of responses from 19 standardized questionnaires and self-reported demographic data, totaling 79 item scores. These questionnaires thoroughly assess a wide range of factors related to insomnia, such as the quality of sleep, routines,

thought patterns, stress levels, coping strategies, emotional control, mood, personality characteristics, and traumatic experiences during childhood. Three separate groups were created from the participant cohort (N = 95): those with sub-clinical insomnia (N = 21, 52% Female), adolescents with clinical insomnia (N = 26, 76% Female), and healthy sleepers (N = 48, 58% Female). To determine insomnia diagnoses, meticulous clinical interviews and adherence to DSM-5 insomnia criteria were used, which is in line with the most recent recommendations for pediatric insomnia [8]. This methodology facilitated a comprehensive and diverse population representation, which is crucial for precise predictive modeling.

Data processing procedures probably included preprocessing activities, including handling missing data, ensuring the data is clean, encoding categorical variables, and standardizing numerical features. This procedure aimed to make the dataset consistent, uniform, and ready for a thorough examination.

Visual and summary methods were used in exploratory data analysis (EDA) to identify patterns, anomalies, and relationships within the dataset. Visualization tools such as correlation matrices and histograms made comprehending the data's fundamental properties and structure easier.

Regarding feature selection—a crucial component in insomnia—the study used methods like correlation analysis and *p*-value computation to determine which features from the questionnaire results are most relevant in influencing insomnia.

Algorithm 1 describes the methodology of the insomnia study analysis.

Algorithm 1 Insomnia Study Analysis

```
Dataset ← LoadDataset
Dataset ← HandleMissingValues(Dataset)
Dataset ← CleanData(Dataset)
Dataset ← EncodeCategoricalVariables(Dataset)
Dataset ← StandardizeNumericalFeatures(Dataset)
VisualizeDataset(Dataset)
SummaryStatistics(Dataset)
RelevantFeatures ← SelectFeatures(Dataset)
Print(RelevantFeatures)
```

B. Selection of Predictive Modeling Techniques

Care must be taken when choosing the proper methods for predictive modeling in assessing insomnia risk. Several machine learning algorithms, such as DT, k-NN, SVM, and NB classifiers, were used. These algorithms were selected based on their ability to identify complex patterns in domains related to insomnia and handle the dataset's complexity. Because decision trees are interpretable, they have been used to specify explicit decision pathways. k-NN, a well-known instance-based learning technique, successfully categorized data points according to their proximity in the feature space.

SVM is a reliable algorithm that has shown usefulness in high-dimensional spaces for regression and classification tasks. NB was chosen as a good probabilistic classifier due to its ease of use and ability to process large datasets. A thorough examination of the dataset and a comprehensive assessment of the insomnia risk factors were made possible by this extensive selection of techniques.

C. Identification of Insomnia Risk Factors

A crucial step in the predictive modeling process was guaranteeing uniformity and consistency in the dataset, which called for extensive data preprocessing. Carefully carried out procedures included handling missing values, cleaning up the data, encoding categorical variables, and standardizing numerical features. Using visualization techniques like correlation matrices and histograms, exploratory data analysis, or EDA, played a crucial role in this process. EDA provided important insights into the structure and characteristics of the dataset by making it easier to identify significant patterns, outliers, and correlations between variables. Feature selection techniques like correlation analysis (see Fig. 4) and *p*-value computations were applied to identify the most relevant features from the questionnaires. The dataset was used to train and assess algorithms during the predictive modeling phase, built upon these particular features.

D. Predictive Modeling and Evaluation

A significant step forward in comprehending and treating insomnia's complexity is applying different machine learning algorithms, such as decision trees, k-NN, SVM, and NB, to predict insomnia-related outcomes based on the chosen features. These advanced techniques made it possible to thoroughly examine the complex interactions between various risk factors and insomnia. Notably, the decision tree algorithm made it easier to identify important pathways in the development of insomnia by offering clear insights into the major factors influencing the condition.

Moreover, proficiently applying k-NN, SVM, and Naïve Bayes algorithms demonstrated the importance of varied analytical techniques in encapsulating the complex characteristics of insomnia risk factors. In summary, this study highlights the potential of predictive modeling to provide critical new understandings of the diagnosis and treatment of insomnia, opening the door to more focused and successful field interventions.

IV. Results and Analysis

This section discusses the results and analysis of the proposed system. Fig. 5 shows the dataset analysis and distribution in various parameters such as gender, age, ethnicity, and Insomnia group.

The diagram in Fig. 6 illustrates the confusion matrix of the feature derived from the correlation coefficient of multiple classifiers. According to the data presented, the DT model demonstrated greater accuracy, yielding higher true positive and false negative outcomes.

The results of the test, derived from the feature's *p*-values, are displayed in Fig. 7. Additionally, the data implies that the DT model exhibited superior accuracy, as evidenced by its higher diagonal values compared to other classifier models.

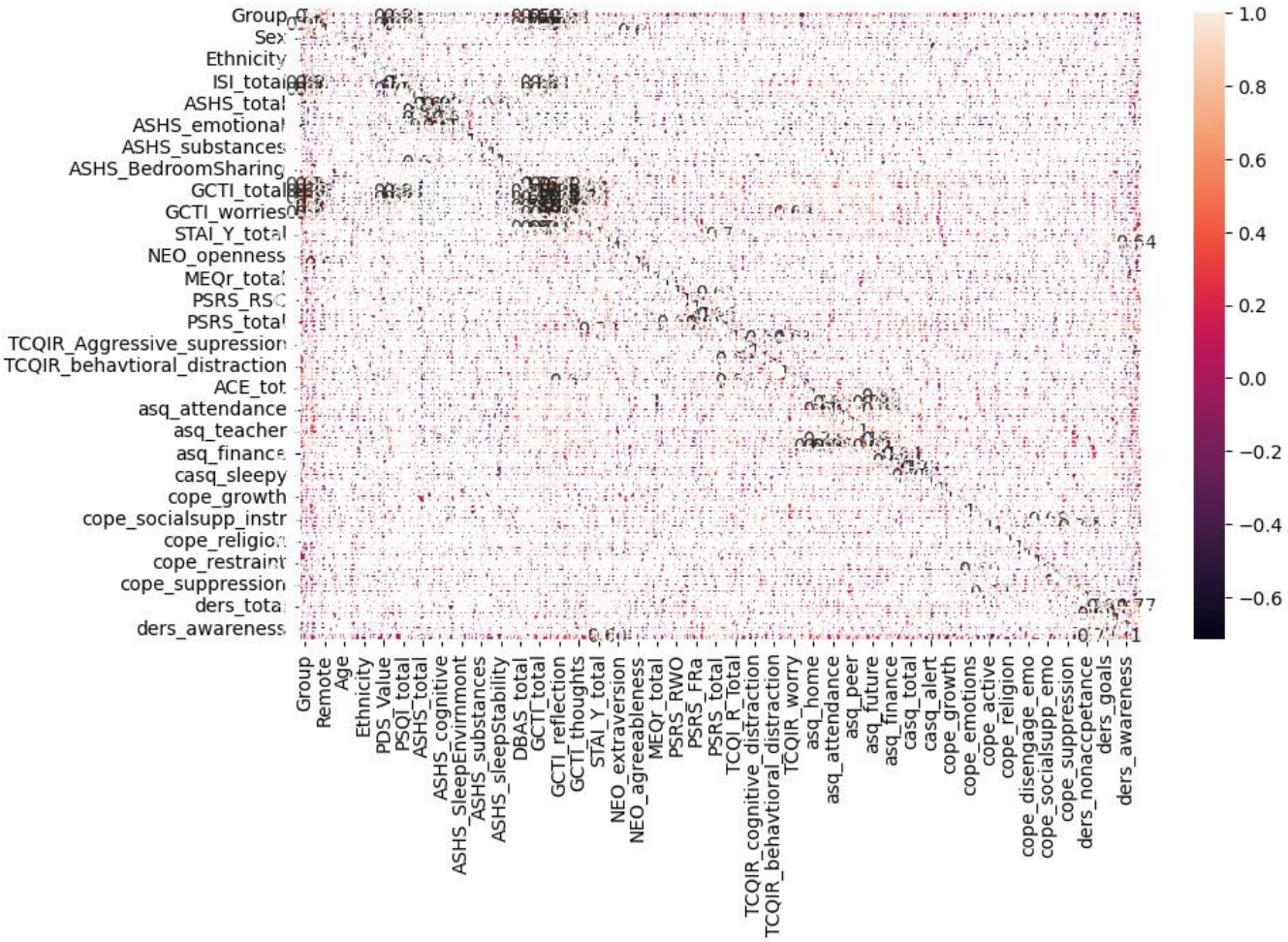

Fig. 4. Correlation coefficient heat map

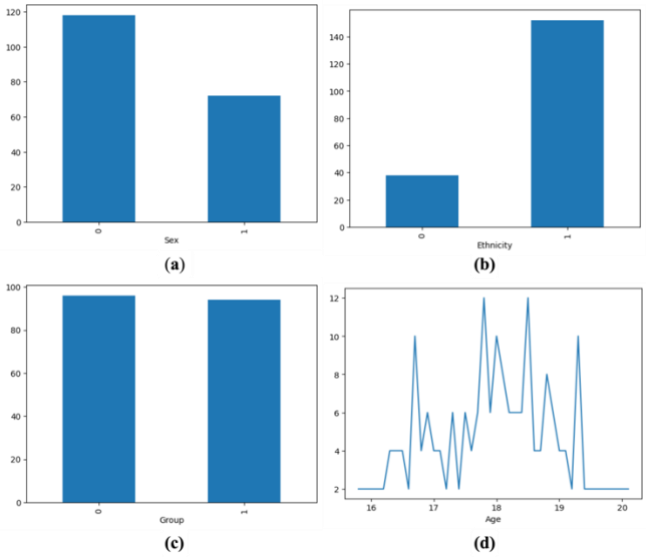

Fig. 5. Data set analysis and distribution for (a) gender, (b) ethnicity, (c) insomnia, and (d) age

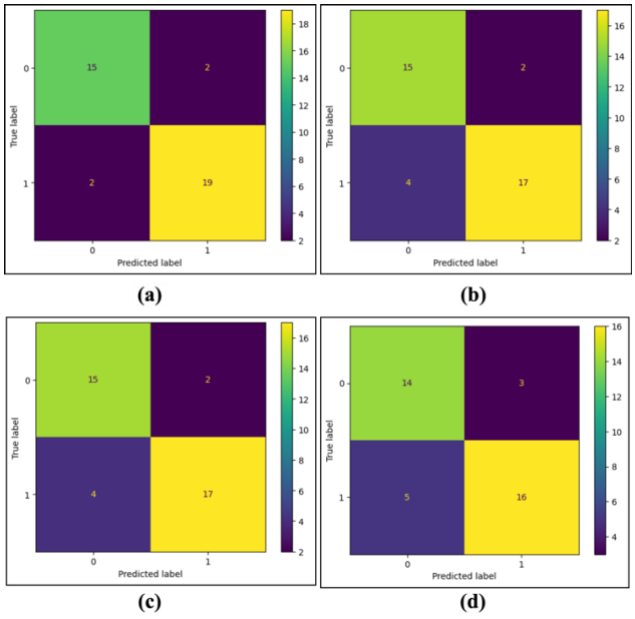

Fig. 6. Confusion matrix of the features extracted from correlation coefficient of (a) DT, (b) k-NN, (c) SVM, and (d) NB

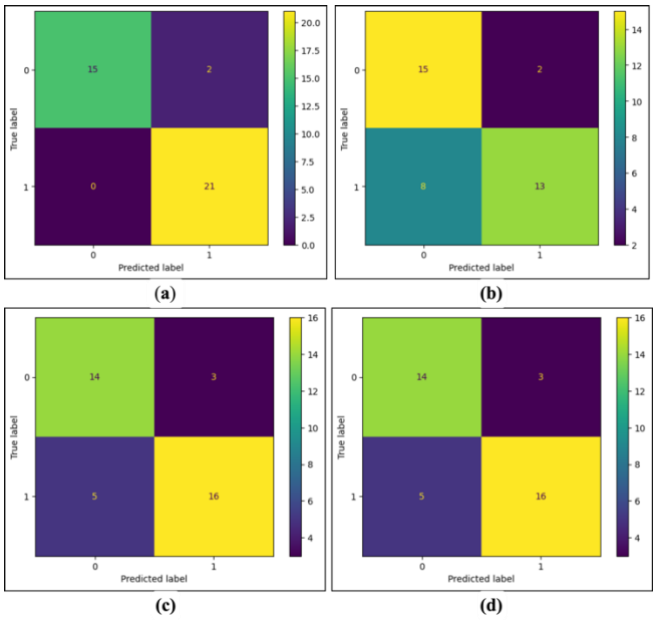

Fig. 7. Confusion matrix of the features extracted from *p*-values of (a) DT, (b) k-NN, (c) SVM, and (d) NB

To investigate the fundamental causes of the different ways in which classifiers with various feature selection techniques perform, more investigation and testing are advised. By gaining a deeper understanding of the complex relationship between feature selection and the outcomes of predictive modeling, such endeavors could lead to the development of more accurate and effective insomnia prediction models.

The non-significant data variables connected to the prediction of insomnia seem to be listed in Tab. 2. The significance of each variable has been assessed using a *p*-value, a metric frequently employed in statistical hypothesis testing. In this case, a *p*-value above a predetermined cutoff point (typically 0.05) suggests that the variable does not have statistical significance when predicting insomnia.

Demographic variables like age and ethnicity are among the first variables examined, producing *p*-values of 0.553 and 0.716, respectively. These findings suggest that for this study, age and ethnicity have no discernible effects on the prediction of insomnia.

Additional examinations cover a variety of behavioral and psychological aspects. For example, the Pittsburgh Sleep Quality Index (PSQI_total) and the Pubertal Development Scale (PDS) have *p*-values of 0.553 and 0.748, respectively, indicating that the information obtained from these measures is not significantly helpful in predicting insomnia. Likewise, evaluations associated with the Athens Insomnia Scale, encompassing factors like sleep environment, daytime sleep, and substance use, exhibit *p*-values between 0.432 and 0.893, signifying an absence of significant correlation with the prognosis of insomnia.

TABLE II. NON-SIGNIFICANCE DATA VARAIBLES OF THE INSOMNIA PREDICTION

Variables	*p*-value
Age	0.553
Ethnicity	0.716
PDS (Pubertal Development Scale_Male/Female)	0.748
PDS_Value (Pubertal Development Scale)	0.72
PSQI_total (PSQI total (Pittsburgh sleep quality index)	0.553
ASHS_SleepEnvirnmont (ASHS Total (Adolescent Sleep Hygiene Scale))	0.893
ASHS_DaytimeSleep (ASHS-Daytime Sleep (Adolescent Sleep Hygiene Scale))	0.109
ASHS_substances (ASHS - Substances (Adolescent Sleep Hygiene Scale))	0.432
GCTI_worries (GCTI General Worries (The Glasgow Content of Thoughts Inventory))	0.365
GCTI_thoughts (GCTI Thoughts About the Environment (The Glasgow Content of Thoughts Inventory))	0.357
PSS_total (PSS Total Score (Perceived stress scale))	0.260
TCQIR_cognitive_distraction (Cognitive Distraction / Suppression TCQI-R (Thought Control Questionnaire Insomnia))	0.054
asq_attendance (Stress of School Attendance ASQ (Adolescent Stress Questionnaire))	0.570
asq_leisure (Stress of School / Leisure Conflict ASQ (Adolescent Stress Questionnaire))	0.430
asq_responsibility (Stress of Emerging Adult Responsibility ASQ (Adolescent Stress Questionnaire))	0.492
cope_disengage_su (Mental Disengagement COPE (Coping skills))	0.811
cope_socialsupp_instr (Seeking Social Support - Instrumental COPE (Coping skills))	0.281
cope_socialsupp_emo (Seeking Social Support - Emotional COPE (Coping skills))	0.080
ders_impulse (DERS Impulse control difficulties (IMPULSE) (Difficulties in Emotion Regulation Scale))	0.958

The Generalized Content Test variables related to thoughts and worries show *p*-values of 0.357 and 0.365, respectively, indicating no significant correlation between the variables and the prediction of insomnia. Additionally, according to the study's parameters, the Perceived Stress Scale (PSS_total) produces a *p*-value of 0.26, suggesting that stress perception may not significantly predict insomnia.

Furthermore, several variables, as assessed by various scales, including the Thought Control Questionnaire-IR, Adolescent Sleep Questionnaire, Coping Responses Inventory, and Difficulties in Emotion Regulation Scale, exhibit *p*-values higher than the traditional significance threshold (0.05). These variables include cognitive distraction, adolescent sleep behaviors, coping mechanisms, social support, and impulse control. These findings point to a lack of meaningful correlations between these behavioral and psychological characteristics and the likelihood of insomnia. The information presented in the table emphasizes how the

variables looked at about insomnia prediction are not significant. However, it's crucial to be aware of the study's limitations and the possibility that more research is required to look into other factors that might be important in predicting insomnia.

The outcomes displayed in Tab. 3 highlight how different predictive models perform when their features are chosen based on correlation coefficients. The DT model consistently demonstrated the highest accuracy, precision, recall, and F1-Score (0.89) among all the classifiers. This shows the DT classifier's robustness and dependability in correctly predicting insomnia-related outcomes based on the chosen features. The precision, recall, F1-Score, and accuracy of the k-NN and SVM models ranged between 0.84 and 0.85, indicating comparable performance levels. This implies that although these models have reasonable predictive power, the DT classifier may be more accurate than them. The NB model is still a good choice for insomnia prediction even though it is marginally less accurate with precision, recall, F1-Score, and accuracy of 0.79. These findings highlight the significance of feature selection and the Decision Tree model's better performance in precisely forecasting patterns of insomnia when compared to the other models under investigation.

TABLE III. EVALUATION OF PREDICTIVE MODELS AFTTER SELECTING FEATURES BY CORRELATION COEFFICIENTS

Classifier	Evaluation Metrics			
	Precision	***Recall***	***F1-Score***	***Accuracy***
Decision tree	0.89	0.89	0.89	0.89
k-NN	0.84	0.85	0.84	0.84
SVM	0.84	0.85	0.84	0.84
Naive Bayes	0.79	0.79	0.79	0.79

The results displayed in Tab. 4 offer an assessment of the predictive models' efficacy after the *p*-value-based feature selection. Interestingly, the DT classifier consistently showed 0.89 accuracy, F1-Score, precision, and recall, indicating its robustness in correctly predicting insomnia-related outcomes. Conversely, the k-NN model performed relatively worse, showing lower recall, accuracy, F1-Score, and precision values at 0.76, 0.75, 0.74, and 0.74, respectively. The SVM and NB models demonstrated a comparatively stable performance, with precision, recall, F1-Score, and accuracy all measuring 0.79. These findings support the significance of feature selection techniques in improving the precision of predictive models for insomnia. While the Decision Tree model maintained high predictive accuracy, the k-NN model demonstrated a decline in predictive performance.

TABLE IV. EVALUATION OF PREDICTIVE MODELS AFTER SELECTING FEATURES BY *P*-VALUE

Classifier	Evaluation Metrics			
	Precision	***Recall***	***F1-Score***	***Accuracy***
Decision Tree	0.89	0.89	0.89	0.89
k-NN	0.76	0.75	0.74	0.74
SVM	0.79	0.79	0.79	0.79
Naive Bayes	0.79	0.79	0.79	0.79

V. DISCUSSION AND CONCLUSION

Several variables, including demographics, influence a complex disorder, insomnia. After examining the connection between demographic factors and insomnia, our research found no evidence of a significant relationship between the prevalence of insomnia and age or race. This result is consistent with earlier studies that indicate insomnia is not age-specific and can occur at any stage of life. Nonetheless, as previous research has shown, our study emphasizes the possible influence of pubertal maturation on the prevalence of insomnia symptoms. This suggests that more investigation is required to understand the relationship between developmental phases and sleep disorders fully.

Predictive modeling requires careful feature selection to identify risk factors linked to insomnia. Two different approaches—the correlation coefficient and the *p*-value—were used in our investigation, leading to the selection 7 and 65 features, respectively. Significantly, both approaches emphasized the significance of several important metrics, such as the Ford Insomnia Response to Stress Test, the Glasgow Content of Thoughts Inventory (GCTI) [10], the Insomnia Severity Index (ISI) [11], the GCTI Sleep Related Anxiety [12], and the GCTI Reflection and Planning [10]. These particular measures provided insightful information about various psychological and cognitive factors contributing to the onset and aggravation of symptoms associated with insomnia.

The measures identified a variety of potential risk factors for insomnia. Since excessive worry and anxiety about sleep frequently prolong insomnia, high scores on the GCTI Sleep Related Anxiety were indicative of people who were likely to develop insomnia. Similarly, high GCTI Reflection and Planning scores suggested an overactive mind marked by constant planning and rumination, making it difficult to fall asleep and stay asleep. The results of the Ford Insomnia Response to Stress Test demonstrated the connection between increased stress reactions and insomnia, with long-term stress being a factor in sleep disorders. Furthermore, a thorough examination of GCTI results revealed particular cognitive patterns linked to insomnia, like negative thinking and cognitive distortions, which worsen sleep disturbances.

The Insomnia Severity Index (ISI), which has higher scores indicating more severe insomnia symptoms and consequent impairments in daily functioning and quality of life, has also come to be recognized as a significant risk factor in and of itself. These results highlight how crucial it is to have a thorough understanding of the psychological and cognitive factors that contribute to insomnia to create customized interventions for those who struggle with sleep disturbances.

Based on feature selection techniques, the performance of several classifiers (see Fig. 6 and Fig. 7), such as DT, k-

NN, SVM, and NB, was assessed in the comparative analysis of predictive modeling approaches. Using correlation coefficients to select features led to consistently high accuracy, F1-score, precision, recall, and accuracy (0.89) for the classifiers. This consistency across metrics and classifiers implied that features selected according to correlation coefficients allowed for precise predictions without appreciable performance differences.

On the other hand, more variable results were obtained with the *p*-value-based feature selection method, especially for the k-NN model, which showed a significant decrease in accuracy, precision, recall, and F1-score (0.76, 0.75, 0.74, and 0.74, respectively). The possible drawbacks of utilizing *p*-values in feature selection were brought to light by this disparity, particularly for some classifiers. The study underlined how crucial feature selection strategies are in determining how predictive classifiers are, highlighting the need for rigorous evaluation of the data type and particular classifier requirements in research and real-world applications.

Age was not found to be a direct risk factor for insomnia; however, the impact of pubertal changes on sleep patterns emphasizes the importance of thorough evaluations that consider developmental milestones and hormonal fluctuations, especially in adolescents. Furthermore, consistent with prior research highlighting the independence of insomnia risk from ethnic backgrounds, our results imply that ethnicity is not a determining factor in the risk of developing insomnia. While social and cultural contexts may indirectly affect sleep habits, our findings highlight the importance of considering various contextual factors when analyzing the connection between ethnicity and insomnia.

Furthermore, we employed various feature selection strategies and predictive modeling techniques to conduct a thorough analysis of insomnia prediction in our study. To create a solid basis for precise predictions, it was essential to carefully preprocess the dataset and identify relevant features using thorough data analysis and feature selection techniques like correlation coefficients and *p*-values.

Evaluation metrics were used to evaluate the performance of various predictive models, such as DT, k-NN, SVM, and NB. These metrics included precision, recall, F1-score, and accuracy. The results showed that the predictive models were consistent when features were chosen using correlation coefficients; high precision, recall, F1-score, and accuracy values were consistently at 0.89. However, the *p*-value-based feature selection approach demonstrated inconsistent results, especially with a significant reduction in k-NN's predictive power. This disparity highlights how intricate feature selection is and how it affects the performance of various classifiers.

This study emphasizes the value of a thoughtful approach to feature selection and the necessity of matching feature selection methods to the needs of various predictive models. Our work advocates for a thorough understanding of the implications of feature selection techniques in creating precise and successful insomnia prediction models, and it acts as a guide for researchers and practitioners. In the context of insomnia research, future studies may explore the underlying mechanisms that underlie the variability in model performance in greater detail, offering additional insights into the optimum feature selection process for robust predictive modeling.

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2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

Analysis of the Trends in Domestic Prices of Petroleum Products in Sri Lanka

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***Abstract*—Crude oil plays a crucial role as a commodity with significant global economic implications. This research project aimed to identify predictive models for forecasting future oil prices in Sri Lanka, utilizing monthly data spanning over 32 years. The analysis involved examining monthly Domestic Prices for five petroleum products, Lanka Petrol 95 (LP95), Lanka Petrol 92 (LP92), Lanka Auto Diesel (LAD), Lanka Super Diesel (LSD), and Lanka Kerosene (LK) covering the period from 1990 to 2021. Three popular time series trend models, namely, Linear Trend Model (LTM), Quadratic Trend Model (QTM) and Exponential Growth Model (EGM), were used on the five petroleum product types. Furthermore, the fitted models were further assessed to find the best fitted models for each type of petroleum product using accuracy measures such as Mean Squared Deviation (MSD), Mean Absolute Deviation (MAD), and Mean Absolute Percentage Error (MAPE). According to the trend analysis results, the exponential growth model was the most suitable for LP95, LP92, LAD, LSD and LK. The results of the study offer practical implications for stakeholders in the Sri Lankan petroleum industry, enabling them to make informed decisions in a volatile global market.**

Keywords—Trend analysis, domestic prices, petroleum products, in Sri Lanka

I. Introduction

Crude oil, often referred to as 'black gold,' is a naturally occurring unrefined petroleum product consisting of hydro-carbon deposits found in underground reservoirs. This raw petroleum, known as crude oil, can be refined into various valuable petroleum products, including diesel, gasoline, and a variety of petrochemicals [1]. As countries around the world experience rapid growth and development, the corresponding surge in demand for crude oil is becoming increasingly evident. The forecast for crude oil prices is a frequent subject of analysis in the global market economy due to its substantial political and economic ramifications, more so than any other commodity. Nevertheless, even though it plays a crucial role in policymaking and economic progress, predicting its price remains difficult because of its intricate and unpredictable pricing patterns [2].

In Sri Lanka, the state-owned Ceylon Petroleum Corporation (Ceypetco) was the sole entity responsible for the importation of crude oil and refined oil, as well as storage, distribution, and retail trade until 2003 [3]. Currently, in addition to Ceypetco, private companies such as the Indian-owned Lanka India Oil (LIOC) and Sinopec, a Chinese oil and gas enterprise, operate numerous fuel stations around the island. These state-owned and private companies distribute petroleum products including petrol, diesel, kerosene and lubricants [3], [5].

The consumption of petroleum products in Sri Lanka has been used in various sectors over the years, including transport, electricity generation, and industrial purposes (such as agriculture, fisheries, and manufacturing) [3]. In Sri Lanka, major petroleum products include diesel, petrol, and kerosene, as well as additional products like LP gas and furnace oil [3]. The pricing of local petroleum is anticipated to be based on a formula considering global prices, currency exchange fluctuations, and additional cost elements [6]. Furthermore, fluctuations in the cost of petroleum exert substantial influence on the prices of commodities and services, given its crucial role as a fundamental intermediate resource in the production process [6]. Therefore, studying the trends and patterns of petroleum products is vital for a country's economic stability, energy security, environmental sustainability, and overall strategic planning. It provides valuable insights that inform policy decisions and prepare nations for potential challenges
related to energy supply and pricing.

This study applies three-time series trend models: The Linear Trend Model (LTM), Quadratic Trend Model (QTM) and Exponential Growth Model (EGM), to five distinct petroleum products, namely Lanka Petrol 95 (LP95), Lanka Petrol 92 (LP92), Lanka Auto Diesel (LAD), Lanka Super Diesel (LSD), and Lanka Kerosene (LK). The aim is to identify the most suitable model that can provide more precise forecasts of petroleum prices in Sri Lanka.

II. Theory and Methodology

A. Data

This study utilized the domestic petroleum prices published by the Ceylon Petroleum Corporation in Sri Lanka. Monthly data spanning a 32-year period (1990 to 2021) was collected. Data from a 30-year period (1990 to 2019) was utilized for analysis, and the remaining price data from the years 2020 and 2021 (2 years) were reserved for validating the trend analysis. Furthermore, the results were obtained using the statistical

software, Minitab 17, and a 5% level of statistical significance was considered.

B. Trend Analysis

Trend analysis is the initial phase of the study, employing a mathematical technique that utilizes historical data to predict future outcomes. Three popular time series trend models, LTM, QTM and EGM were applied in this research.

a) Linear Trend Model (LTM): A linear trend model in time series analysis is a mathematical representation used to illustrate how a variable relates to time. It operates on the assumption that the variable undergoes a consistent, steady change over time. In other words, when graphically representing the data, it would follow a straight-line pattern.

The equation for a linear trend model typically takes the form:

$$y_t = B_0 + B_1 t + \varepsilon_t \quad (1)$$

where y_t represents the value of the variable at time t, B_0 is the intercept term, which represents the starting value of the variable, $B_1$is the slope, indicating the rate of change per unit of time, t is time and ε_t represents the error term, accounting for random fluctuations or noise in the data [7].

b) Quadratic Trend Model (QTM): A quadratic trend model in time series analysis is a mathematical representation employed to depict how a variable relates to time in cases where the changes over time do not follow a straight-line pattern. Rather, the data displays a curved or parabolic trend.

The equation for a quadratic trend model typically takes the form:

$$y_t = B_0 + B_1 t + B_2 t^2 + \varepsilon_t \quad (2)$$

where y_t represents the value of the variable at time t, B_0, B_1 and B_2 are coefficients that need to be estimated from the data, t is time, t^2 represents the square of time, introducing the curved aspect of the model and ε_t represents the error term, accounting for random fluctuations or noise in the data [7].

c) Exponential Growth Model (EGM): The exponential growth model in time series analysis is a mathematical framework employed to depict a scenario in which a variable experiences an accelerating increase or decrease over time.

The equation for an exponential growth model typically takes the form:

$$y_t = B_0 B_1^t + \varepsilon_t \quad (3)$$

where y_t represents the value of the variable at time t, B_0 and B_1 are coefficients that need to be estimated from the data, t is time and ε_t represents the error term, accounting for random fluctuations or noise in the data [7].

When assessing the depiction of the time series, particularly the time series plot, the choice of model fitting is determined by its visual characteristics. Linearity, if observed in the representation, will lead to the application of the linear trend model. In cases where curvature or an exponential trend is demonstrated, the quadratic or exponential model will be employed, respectively [7].

Additionally, the fitted models were evaluated using various accuracy measures, including Mean Squared Deviation (MSD), Mean Absolute Deviation (MAD), and Mean Absolute Percentage Error (MAPE). Furthermore, the actual prices and forecasted prices were compared using the Pearson Correlation Coefficient to validate the fitted models [7], [8].

MSD is a commonly employed measure for assessing the fit of time series values. Smaller values indicate a better fit. MAD gauges accuracy in the same units as the data, providing a tangible sense of the error magnitude. MAD is less influenced by outliers compared to MSD. Smaller values indicate a better fit. MAPE measures accuracy as a percentage of the error, making it easy to understand. For example, a MAPE of 5 implies that, on average, the forecast deviates by 5%. Lower values signify a more accurate fit. When a single model doesn't yield the lowest values for all three accuracy measures, MAPE is typically the preferred metric [9].

III. Results and Discussion

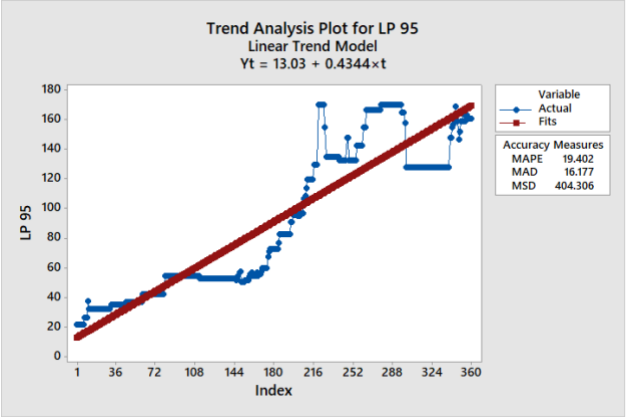

Fig. 1. Trend analysis plot (LP95, LTM)

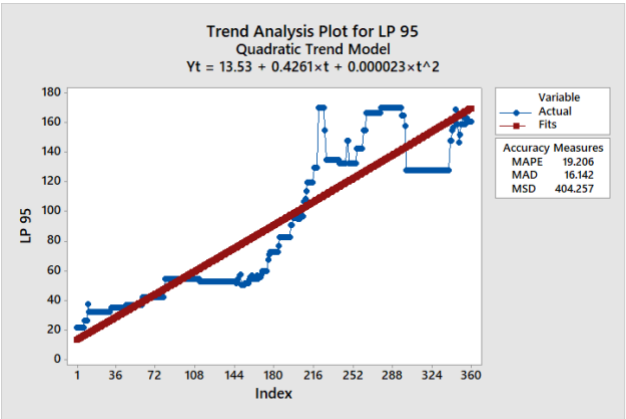

Fig. 2. Trend analysis plot (LP95, QTM)

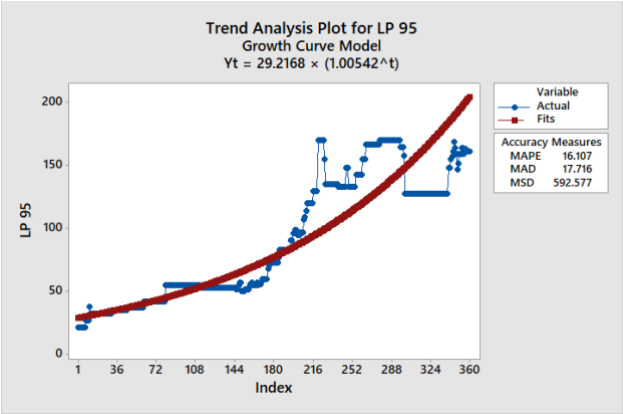

Fig. 3. Trend analysis plot (LP95, EGM)

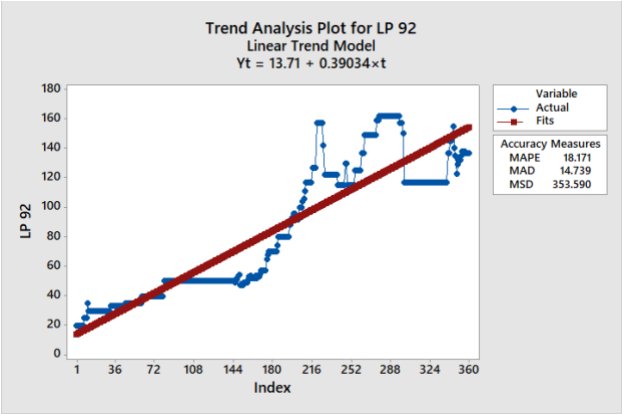

Fig. 4. Trend analysis plot (LP92, LTM)

TABLE I
ACCURACY MEASURES FOR LP95

Accuracy Measure	LTM	QTM	EGM
MAPE	19.402	19.206	16.107
MAD	16.177	16.142	17.716
MSD	404.306	404.257	592.577

Fig 1, 2 and 3 illustrates the fitted trend models, namely LTM, QTM, and EGM, for LP 95. A comparison of the accuracy measures for LP 95, in Table I revealed that both LTM and QTM exhibit lower values for MAD and MSD in comparison to the accuracy measures of EGM model. However, the EGM model showed a lower MAPE of 16.107 when compared to MAPE values of LTM and QTM. Therefore, the EGM model stands out as the best fit due to its superior accuracy measures. The mathematical expressions for the fitted models are as follows:

LTM:

$$y_t = 13.03 + 0.4344t \quad (4)$$

QTM:

$$y_t = 13.53 + 0.4261t + 0.000023t^2 \quad (5)$$

EGM:

$$y_t = 29.2168 \times 1.00542^t \quad (6)$$

TABLE II
ACCURACY MEASURES FOR LP92

Accuracy Measure	LTM	QTM	EGM
MAPE	18.171	19.263	16.164
MAD	14.739	14.891	16.599
MSD	353.590	352.132	537.526

Fig 4, 5 and 6 illustrates the fitted trend models for LP 92. The results presented in Table II shows the accuracy measures for LTM, QTM, and EGM for LP 92. Among these models, the EGM stands out with the lowest MAPE value of 16.164, while both LTM and QTM exhibit lower values for MAD and MSD when compared to measurable values of EGM. Therefore, the

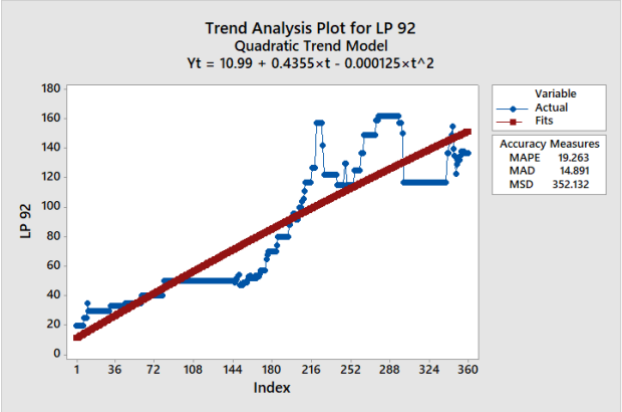

Fig. 5. Trend analysis plot (LP92, QTM)

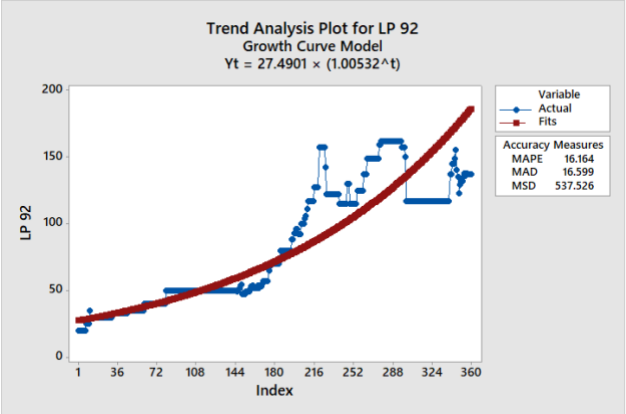

Fig. 6. Trend analysis plot (LP92, EGM)

best fitted model is EGM. The corresponding trend models are as follows.

LTM:

$$y_t = 13.71 + 0.39034t \quad (7)$$

QTM:

$$y_t = 10.99 + 0.4355t + 0.000125t^2 \quad (8)$$

EGM:

$$y_t = 27.4901 \times 1.00532^t \quad (9)$$

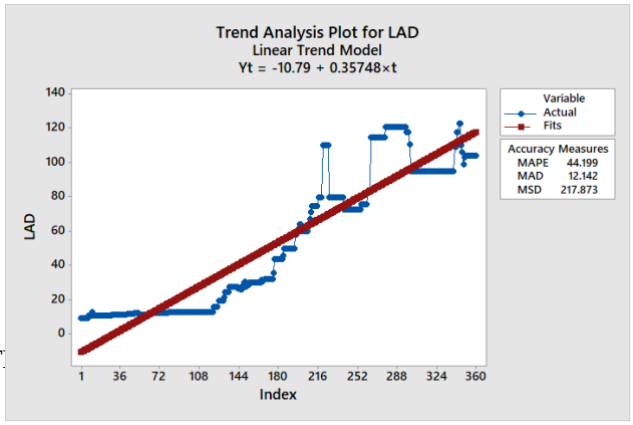

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Fig. 7. Trend analysis plot (LAD, LTM)

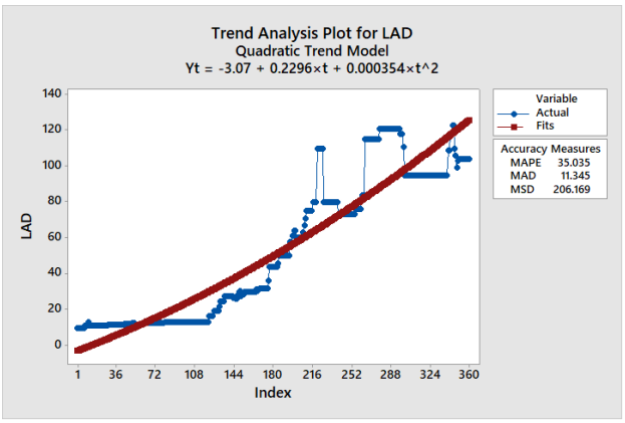

Fig. 8. Trend analysis plot (LAD, QTM)

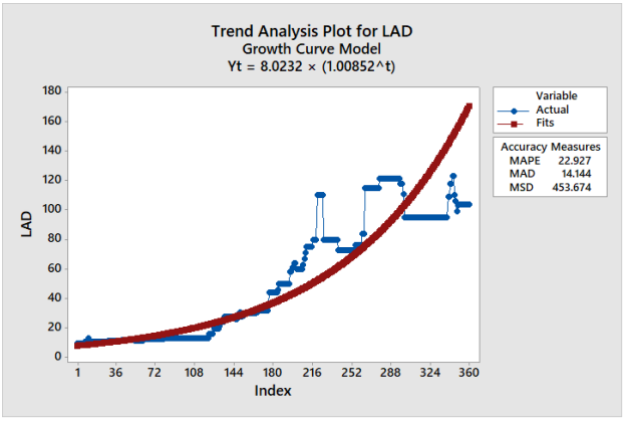

Fig. 9. Trend analysis plot (LAD, EGM)

Fig 7, 8 and 9 illustrates the fitted trend models for LAD. Accuracy measures for the product LAD are represented in Table III. Both MAPE and MAD values, 22.927 and 14.144

TABLE III
ACCURACY MEASURES FOR LAD

Accuracy Measure	LTM	QTM	EGM
MAPE	44.199	35.035	22.927
MAD	12.142	11.345	14.144
MSD	217.873	206.169	453.674

respectively, are lower in the EGM model compared to LTM and QTM. According to that EGM is the best fitted model. The corresponding trend models for LTM, QTM, and EGM are as follows:

LTM:

$$y_t = -10.79 + 0.35748t \quad (10)$$

$$y_t = -3.07 + 0.2296t + 0.000354t^2 \quad (11)$$

EGM:

$$y_t = 8.0232 \times 1.00852^t \quad (12)$$

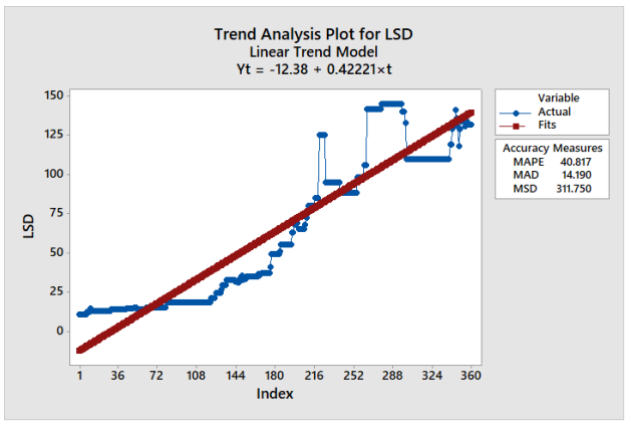

Fig. 10. Trend analysis plot (LSD, LTM)

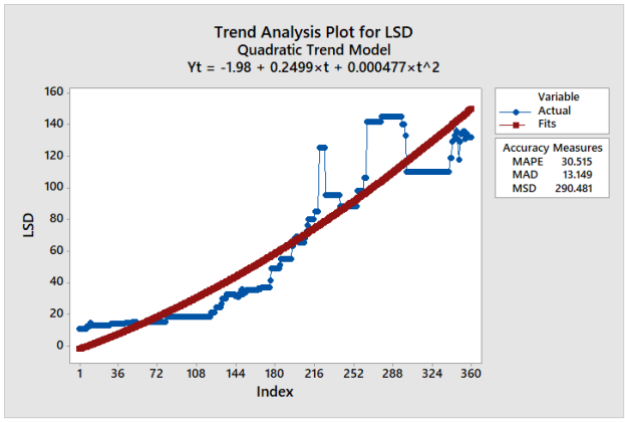

Fig. 11. Trend analysis plot (LSD, QTM)

Fig 10, 11 and 12 illustrates the fitted trend models for LSD. The lowest MAPE value (19.755) was associated with the EGM in Table IV for the product LSD, and QTM exhibits the

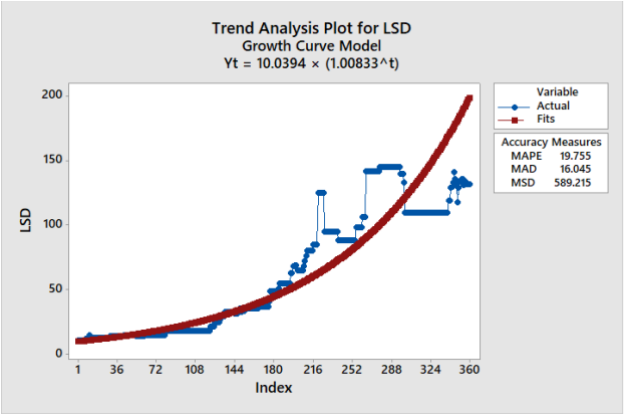

Fig. 12. Trend analysis plot (LSD, EGM)

TABLE IV
ACCURACY MEASURES FOR LSD

Accuracy Measure	LTM	QTM	EGM
MAPE	40.817	30.515	19.755
MAD	14.190	13.149	16.045
MSD	311.750	290.481	589.215

lowest MAD value (13.149) when compared with measured values of other models. Then, EGM emerges as the preferred model for forecasting the price of LSD. The fitted trend models for LSD are as follows:

LTM:

$$y_t = -12.38 + 0.42221t \quad (13)$$

QTM:

$$y_t = -1.98 + 0.2499t + 0.000477t^2 \quad (14)$$

EGM:

$$y_t = 10.0394 \times 1.00833^t \quad (15)$$

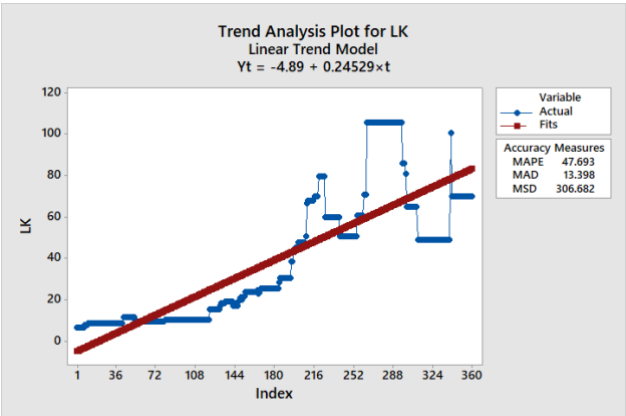

Fig. 13. Trend analysis plot (LK, LTM)

Fig 13, 14 and 15 illustrates the fitted trend models for LK. Table V represents the details of accuracy measures of LK and the MAD values for all the models are nearly equal. EGM has the least MAPE value (27.692) and MSD is less in both LTM

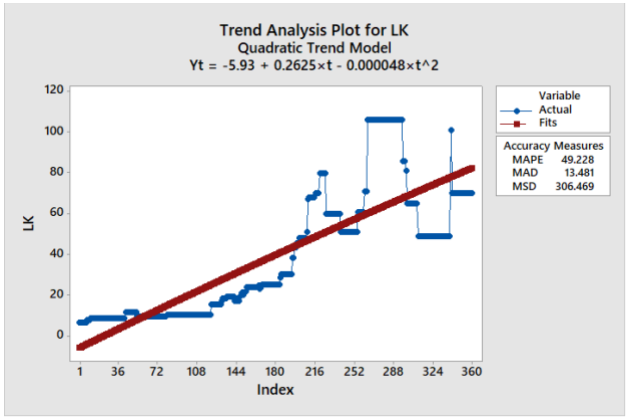

Fig. 14. Trend analysis plot (LK, QTM)

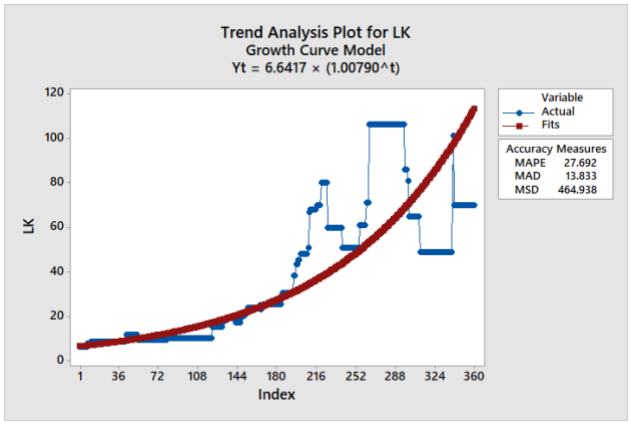

Fig. 15. Trend analysis plot (LK, EGM)

TABLE V
ACCURACY MEASURES FOR LK

Accuracy Measure	LTM	QTM	EGM
MAPE	47.693	49.228	27.692
MAD	13.398	13.481	13.833
MSD	306.682	306.469	464.938

and QTM than in the EGM. Most suitable model to forecast the prices of LK is the EGM. Fitted tend models LTM, QTM and EGM are given below.

$$y_t = -4.89 + 0.24529t \quad (16)$$

QTM:

$$y_t = -5.93 + 0.2625t + 0.00048t^2 \quad (17)$$

EGM:

$$y_t = 6.6417 \times 1.00790^t \quad (18)$$

Table VI shows the correlation analysis between the actual prices of all petroleum products for the years 2020 and 2021, based on 24 monthly prices, and the forecasted prices by each model. The results exhibit a high correlation between the forecasted prices by the fitted models LTM, QTM, and EGM and the actual monthly prices of petroleum products of LP 95, LP 92, LAD, LSD, and LK.

TABLE VI
CORRELATION BETWEEN ACTUAL PRICES AND THE FORECASTED PRICES OF LP92, LAD, LSD AND LK

Petroleum Product	LTM	QTM	EGM
LP95	0.775	0.775	0.783
LP92	0.775	0.773	0.783
LAD	0.751	0.753	0.765
LSD	0.761	0.764	0.775
LK	0.751	0.750	0.764

Since the current global economy depends mostly on fuels, the global oil market is more complicated than it appears, and the price of oil is dependent upon many different factors. Present study analyzed the domestic petroleum price in Sri Lanka, and there are many factors that affect it, such as the inflation rate, economic growth rate, gross domestic growth rate, dollar exchange rate, OPEC (The Organization of Petroleum Exporting Countries), supply and demand, restrictive legislation, political unrest, financial markets, weather, etc. [10, 11].

IV. CONCLUSION

This study has performed the trend analysis for domestic prices of petroleum products in Sri Lanka using monthly data through the years 1990 to 2021. The results concluded the best models which can be used to predict future oil prices. The results of the study revealed that the best fitted model for LP95, LP92, LAD, LSD and LK was EGM. These outcomes not only contribute valuable insights to the domain of energy economics but also offer practical implications for stakeholders in the Sri Lankan petroleum industry, enabling them to make informed decisions in a volatile global market.

ACKNOWLEDGMENT

Authors would like to thank Ms. Warunika Hippola and Ms. Udya Devaraj at Sri Lnaka Technological Campus for the support extended during the study.

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2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

How Do Mathematics Teachers Utilize Their Specialized Content Knowledge In Teaching The Concept of Derivative?

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***Abstract*—The Specialised Content Knowledge (SCK) is an important sub-domain under Mathematical Knowledge for Teaching (MKT) framework that describes the mathematical content knowledge that is unique to the profession of teaching and not necessarily required by other professions in which mathematics is used. Research on SCK in the context of secondary education is still underdeveloped while SCK of in-service teachers have also received limited attention. The current study investigates the SCK of Sri Lankan in-service secondary mathematics teachers in teaching an important Calculus concept in G.C.E. (Advanced Level) combined mathematics curriculum: the concept of Derivative. Lessons of ten mathematics teachers from seven schools were observed. The data comprises of field notes and video recordings of lessons and these video recordings were transcribed verbatim for analysis. Transcripts of lessons were analysed through the lens of Ball's MKT framework while placing more emphasis on SCK sub-domain. Analysis of data identified four different components that describe SCK in teaching the concept of derivative, namely: SCK-PK (Building new knowledge on prior knowledge), SCK-MR (Multiple Representations), SCK-MJ (Mathematical Justifications), and SCK-ML (Mathematical Language). Teachers exhibited each SCK component in varying degrees of proficiency. Majority of teachers elicited their content knowledge under SCK-MR and SCK-ML components while gaps were noticed in SCK-MJ and SCK-PK components. This study sheds light on the current status of G.C.E. (Advanced Level) combined mathematics teachers with respect to SCK and provides insights for planning teacher education programs and workshops.**

Keywords—Mathematical knowledge for teaching, specialized content knowledge, The concept of derivative, secondary teaching

I. INTRODUCTION

Teacher knowledge is an essential ingredient in teaching mathematics and it is empirically evident that teacher knowledge has a direct impact on quality of instruction and student achievements [1, 4]. Due to this reason, understanding the knowledge demands in teaching mathematics has gained an attention among educators during the past few decades. However, due to its multi-dimensional nature, assessing teacher knowledge is often a challenging task. In the past, teacher knowledge has been assessed directly, through proxy variables such as degrees obtained, number of courses completed or standardized test scores of teachers [1, 4]. Most academics realized such measures as problematic [1] as they do not sufficiently reflect teacher's subject matter content knowledge *for* teaching mathematics. However, a new line of thinking came into light with Shulman's [2] argument that "knowledge for teaching mathematics" is different from "knowledge for doing mathematics". Shulman [2] identified that the subject matter knowledge and pedagogical knowledge that a teacher must possess are not mutually exclusive but is a blended special set of skills and knowledge in order to teach, which he coined as Pedagogical Content Knowledge (PCK). His seminal work on PCK sparked an interest in many researchers to investigate content knowledge *for* teaching and various models emerged to define and categorize the knowledge demands to carry out the work of teaching mathematics. Such categorization of teacher knowledge permits educators and policy makers to understand the current standing of mathematics teachers and to provide better insights into planning teacher education and professional development programs.

A. MKT Model

Shulman's [2] seminal work on PCK was brought into and adopted by a Ball and her colleagues [3], a group of researchers at Michigan University. They conducted a longitudinal research to ascertain the type of content knowledge that matters for teaching and revealed that the typologies suggested by Shulman [2] as vital to leverage the content knowledge of a teacher as the technical knowledge in defining teaching as a profession. Based on the working definition for Mathematical Knowledge for Teaching (MKT) as "mathematical knowledge needed to carry out the work of teaching mathematics" [3, p. 395], they collected and analysed the work carried out by teachers (a job analysis or a bottom-up practice based approach) throughout a year by way of video and audio tapes of lessons, students work, homework, lesson plan, etc. Their final model, the MKT framework is a practice-based theory that encapsulates the mathematical knowledge needed to perform the recurrent tasks of teaching mathematics. Although MKT theory was first developed in the U.S. context for primary teachers, it was later adapted to assess the MKT of elementary and secondary teachers and has been widely used in many other continents. The current study will opt for Ball et al.'s MKT model as an analytical framework due to its' comprehensive structure and empirical validity in assessing teacher knowledge.

According to MKT framework, teacher knowledge demands in teaching mathematics can be categorized into two main domains (see Fig. 1): Subject Matter Knowledge (SMK) and Pedagogical Content Knowledge (PCK). Each

of these domains consists of three sub-domains. Sub-domains under SMK are Common Content Knowledge (CCK): the mathematical knowledge commonly used by settings other than teaching, Specialised Content Knowledge (SCK): the mathematical knowledge that is unique to the profession of teaching, and Horizon Content Knowledge (HCK): a peripheral vision of mathematics or the knowledge of how the currently taught content is connected to larger mathematical ideas and structures. Sub-domains that belong to PCK are, Knowledge of Content and Teaching (KCT): the knowledge in planning and designing the instruction, Knowledge of Content and Students (KCS): the knowledge that intertwines the knowledge about mathematics with the knowledge about students such as anticipate students' reactions to a particular task, student's common mathematical errors and misconceptions and finally, Knowledge of Content and Curriculum (KCC): knowledge on instructional materials, curriculum and programs.

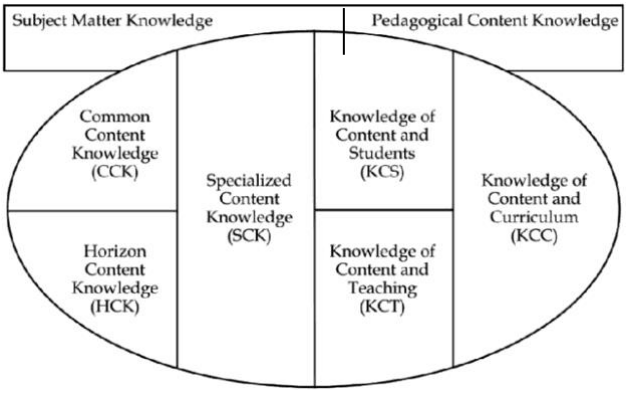

Fig. 1. Domains and Sub-domains of MKT Model [3]

Our study aimed at investigating the SCK in the context of senior secondary teaching in Sri Lanka. There were several underlying reasons opting for SCK over other domains in MKT framework. Scholars [3, 4] have placed a special interest on the study of SCK due to its relative importance in teaching and have acknowledged the need of future work due to its contribution for content preparation in teacher development. In addition, SCK encompasses "purely" mathematical knowledge which is unique to the profession of teaching. Hence, studies on SCK allow researchers to ascertain the topic specific content knowledge of teachers and provide a direction for educators and policy makers to better orient teacher education, development and training initiatives for prospective teachers.

B. Specialised Content Knowledge (SCK)

The Specialised Content Knowledge (SCK) is an important sub-domain (out of six sub-domains – see Fig. 1) under MKT framework which describes the content knowledge that is unique to the profession of teaching and "not typically needed for any purpose other than teaching" [3, p. 400]. Ball, Thames and Phelps [3] listed tasks of teaching that are associated with SCK which includes (a) linking representations to underlying ideas, (b) finding examples to make a mathematical point, (c) giving mathematical explanations, (d) presenting mathematical ideas, (e) asking productive mathematics questions, (f) inspecting equivalencies, (g) choosing or developing usable definitions, etc. It also includes the way teacher conducts "error analysis" - recognizing and rectifying student errors promptly, appraising and analysing unconventional solution methods that students present, sizing up the source of error, justifying generalizations, etc. As mentioned in [3, p. 397] "this is the type of work that teachers must do rapidly, often on the fly, because in a classroom, students cannot wait as a teacher puzzles over the mathematics". However, the description of Ball, Thames and Phelps [3] for SCK does not restrict to have such knowledge for mathematicians, but emphasized that having such knowledge is *not essential* for mathematicians to do their jobs while it is *compulsory* for teachers in teaching mathematics. According to [5], an accountant and a doctor do not necessarily require a mathematical reasoning for using common denominator when adding two fractions (although they have all rights to know it), but it is indeed a natural work in a classroom teaching. One of the easiest ways to recognize SCK over other knowledge domains (especially from PCK) is that SCK is primarily based on the knowledge of the content and doesn't necessarily expect having additional knowledge about students or teaching [3].

C. Mathematics in Sri Lankan Advanced Level Curriculum

Advanced Level (A/L) combined mathematics syllabus in Sri Lanka constitutes of two components: Pure and Applied Mathematics. Major topics covered under pure mathematics are Algebra, Calculus, Coordinate Geometry and Trigonometry out of which Calculus has gained far more attention in the curriculum due to several reasons. Firstly, calculus is a fundamental branch in mathematics and is a pre-requisite for many advanced topics in mathematics. Secondly, calculus section carries a significant weightage in the General Certificate of Education A/L examination, contributing to more than 25% of total marks. Thirdly, calculus is a completely new area for collegiate students as they learn it for the first time at A/L. All these facts signify the importance of calculus in A/L curriculum. Calculus comprises of four sections: Limits, Derivatives, Application of Derivatives and Integration. However, its inherent abstract nature, mathematical jargons and symbols makes it difficult for beginners to understand. Therefore, a special attention is required to ensure that these concepts are taught well at A/L classrooms. The current study aimed at investigating the teacher knowledge based on the introductory lesson of the derivative and to ascertain teachers' level of SCK elicited during instruction. This study will answer two research questions given below.

1. What are the components of SCK in teaching the concept of derivative for secondary students?
2. In the identified components of SCK, what are the strengths and weaknesses demonstrated in the instruction?

II. METHODOLOGY

A. Participants

This study followed a qualitative approach and the data was drawn from a two year funded research on exploring the Mathematical Knowledge for Teaching (MKT) of A/L mathematics teachers in teaching limits and derivatives. First, a list of potential participants was prepared based on referrals from university lecturers, teachers and educators who conduct professional development programs for teachers. Neither teaching experience nor any other special characteristic was considered in selecting participants. Next, these participants were contacted to check their interest on

taking part in the study. At the time we initiated this study (in year 2021), majority had already completed limit and derivative lessons. Therefore, selection process had to be iterated until the stipulated number was met. Finally, 16 advanced level mathematics teachers working in 11 different government and private schools across three districts in Sri Lanka gave their consent to participate in this two year research project. Ten out of 16 teachers participated in teaching the "introduction to the derivative", a topic which is usually taught during the 3rd term of year 12. Usual time allocation to teach the introductory lesson of derivatives is six periods (6 x 40 minutes).

B. Data Collection

Data were primarily collected through lesson observations and field notes. Collection of data did not disturb the usual flow of how curriculum is lined-up in a usual academic year. Instead, classes were visited as and when the particular lesson was being conducted. Through continuous follow-ups with teachers, a schedule was prepared and lesson observations were conducted accordingly. Two teachers conducted their lessons in English medium while other teachers did their lessons in Sinhala medium. These lessons were video recorded for the purpose of transcribing and indebt analysis. Through manual transcribing (verbatim) process, all video recordings were converted into text file format which contain teacher-student conversations (with line numbers), time stamp, utterances and gestural information as well as the diagrams, tables and other data captured through the audio. In order to maintain participants' privacy, all the teachers were given pseudonyms (from A to P).

C. Data Analysis

Lesson transcripts were analyzed qualitatively and Ball, Thames and Phelps's [3] MKT framework was primarily employed as the guiding theory in analysing these transcripts. To answer the first research question of "what are the components of SCK in teaching the derivative for secondary students", we first scanned the data through the lens of MKT framework to explore the tasks of teaching belonging to the six different MKT domains. An in-depth understanding of each subdomain in MKT framework was required in order to differentiate and distinguish SCK from other sub-domains.

After reading the transcripts several times to understand the general behaviour of the data, we identified meaningful chunks of words (A chunk consists of statements, explanations, a conversation between teacher and students, questions asked, etc.) in such a way that such chunk of words is small enough to explore components of SCK and large enough to explore at least one or two SCK components. At this stage, notes have been taken based on identified patterns and similarities and reflected back to the research question to identify initial codes. For instance, if a unit of analysis (or chunk of words) describes teacher *work* on graphical representation of the derivative, such unit was coded as "graphical representation". However, if that chunk of words also illuminates the teacher knowledge on choosing examples wisely to make an important mathematical point, that chunk was coded again as "example to make mathematical point". Hence, a single unit of analysis could have more than one code. However, if this word chunk describes teacher knowledge that belongs to any other sub-domain other than SCK, such chunks directly coded based on the name of that sub-domain(s) (e.g. HCK, CCK, KCS, KCC or KCT). For example, if a teacher discusses about structure of the curriculum, such word chunk was given a code as KCC as the teacher knowledge on curriculum structure belongs to KCC domain. This method facilitated in filtering out SCK easily from the rest of the sub-domains. However, a deep understanding of the MKT framework was needed to undertake this process as there were instances where overlapping occurs (e.g. SCK with CCK or SCK with KCT).

While using MKT framework as a lens to explore data, we also utilized an inductive-deductive mixed approach to identify *open* and *priori codes* to explore patterns of data read through the transcripts.

III. RESULTS

After a series of refinements, we were able to identify various tasks of teaching that reflect MKT of a teacher. However, to be in line with the scope and the research questions of the study, we will be reporting the routine but unique tasks of teaching that require SCK to execute. Hereafter, we will refer these routine tasks of teaching as *components* of SCK. Tab. 1 outlines the components of SCK that emerged during the qualitative analysis.

TABLE I. COMPONENTS OF SCK IN TEACHING THE DERIVATIVE

Component	Meaning
SCK-PK:Building new knowledge on prior knowledge	The content knowledge of a teacher in building new knowledge on prior knowledge.
SCK-MR: Multiple representations	The content knowledge of a teacher in using symbolic, graphical and verbal representations.
SCK-MJ: Mathematical Justification	The content knowledge of a teacher in providing valid mathematical justifications for actions undertaken during instruction.
SCK-ML: Mathematical Language	The content knowledge of a teacher in using topic specific lexical and natural language.

SCK-PK represents the knowledge of the teacher in activating and linking prior knowledge with new knowledge. Ball, Thames and Phelps [3] listed "connecting a topic being taught to topics from prior to future years" as a task that demands SCK and this aligns with the SCK-PK of the current study. SCK-MR is commonly emphasized in general educational research, MKT research [3, 6] and educational standards such as NCTM [5] as a key component in teaching. Ball, Thames and Phelps [3] identified, *linking representations to underlying ideas and to other representations* as a teaching task requiring SCK and [6] highlighted *representation* as one of the central components of SCK. The component, SCK-MJ centers on how teachers utilize their SCK to justify mathematical procedures, explain conceptual meaning and reasoning, etc. Justification has been vastly emphasized as a significant aspect in teaching mathematics [3, 6]. Moreover, teachers' expertise in explaining and justifying mathematical ideas (e.g. the rationale behind inverting and multiplying to divide by fractions) reflects their level of SCK [3]. SCK-ML was also emerged through data which aligns with the SCK component noted by Ball, Thames and Phelps [3] who once

mentioned "teachers, however, must be able to talk explicitly about how mathematical language is used (e.g. how the mathematical meaning of edge is different from the everyday reference to the edge of a table)" [3, p.400].

Despite contextual differences, the alignment between SCK components in our study (as listed in Table 1) and Ball, Thames and Phelps's [3] empirical results are noteworthy. These components strengthen the applicability of MKT model (developed based on primary teachers in United States) to the secondary teaching context in Sri Lanka with a few refinements. In the next section, we discuss the strengths and gaps revealed under each SCK component in order to answer the second research question of this study.

A. SCK-PK: Building New Knowledge on Prior Knowledge

As illustrated in Fig. 2, learning the concept of derivative demands a significant portion of prior knowledge on functions, algebra, trigonometry, etc. which are logically interwoven with the concept of derivative.

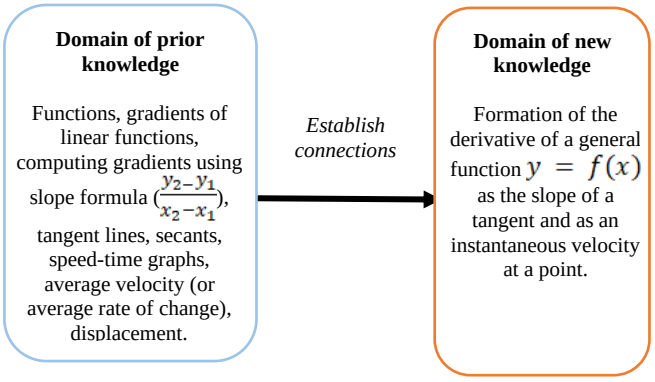

Fig. 2. Linking prior knowledge to new knowledge

However, data provides evidence that although teachers recalled certain mathematical ideas as an when it was required, majority of them were not particularly keen on activating prior knowledge at the very beginning of the lesson. Instead, most of them initiated the lesson by directly deriving the formal definition of derivative. Only two teachers (teachers A and I) activated topic specific prior knowledge, however their focus on establishing explicit links between the existing and new knowledge was not adequate. As a result of that, important learning opportunities were missed and learning was deprived of establishing meaningful connections across the mathematical concepts. Information becomes meaningful when the brain links new information with the prior knowledge and teachers as moderators could expedite this process by recalling prior topics. If teachers fail to do so, it may encourage rote learning as new learning occurs independently with no reference to prior knowledge. This section of the analysis clearly points the significant gaps in teachers' SCK in recalling the essential prior knowledge to learn the concept of derivative, and therefore SCK-PK deserves much attention in secondary context.

B. SCK-MR: Multiple Representations

When a mathematical concept is represented in a variety of forms, it provides learners an opportunity to observe and better understand a concept through multiple facets which could promote deep learning of abstract mathematical concepts. Derivative is a concept that can be introduced in variety of forms. Similar to the illustration of teacher E (see Fig. 3), all other participating teachers took efforts to integrate verbal, graphical and symbolical representations interchangeably when presenting the definition of the derivative.

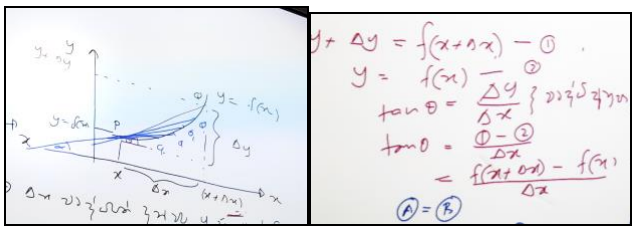

Fig. 3. Graphical and Symbolic representations–Work of teacher E

Graphical method is considered as a powerful form of representation that enables students to visualize abstract mathematical concepts in a concrete manner. A prominent observation was that the majority of the teachers represented the concept of derivative through a series of well-elaborated diagrams and most of them moved flexibly within and in between other modes of representations. Fig. 4 depicts the diagrams used by four teachers to explain the concept of derivative.

However, we also noticed few incomplete diagrams (in the cases of teacher A, N, O & I) which lacked basic features in representing the derivative. For instance, as evident in Fig. 4, teachers A and I did not draw series of secant lines, but used hand movements and verbally explained how secant line (e.g *PQ*) gradually approaches "the tangent line at *P*". In addition to that, as in Fig. 5, teacher N's graphical demonstration did not contain the basic features to represent the derivative and she also failed to illustrate the same verbally. Instead, she followed a direct approach to introduce $\frac{\Delta y}{\Delta x}$ with no reference to the gradient of the secant line or tangent line. Such representations tend to add less visibility to the concept and tend to leave doubts or induce misconceptions among learners. According to the analysis, diagrams used by some teachers (Teachers C, E and J) elicited more elaborative power when compared to the diagrams used by other teachers (Teachers A, N, O & I). The gaps in SCK-MR of teachers A, I and N were largely evident through their graphical illustration of the derivative.

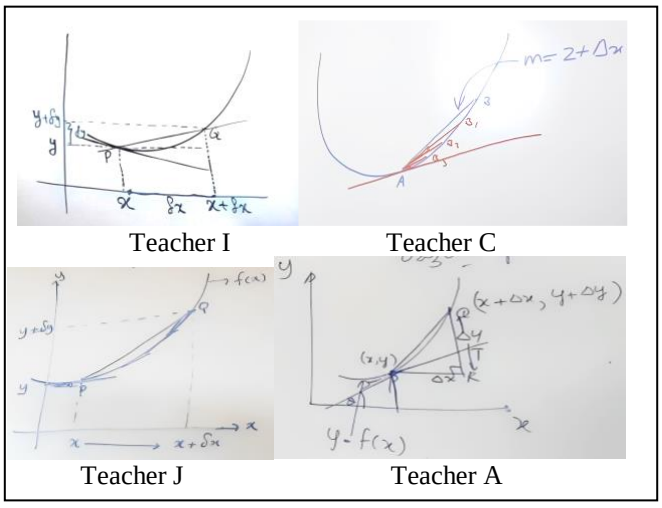

Fig. 4. Diagrams used by four teachers to introduce the derivative

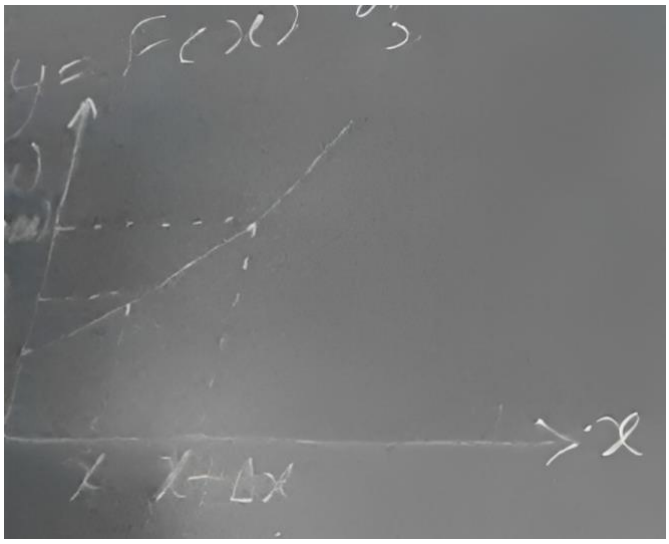

Fig. 5. Diagram used by teacher N to introduce the derivative

Symbolic representation also plays a pivotal role in presenting the definition of the derivative $\frac{dy}{dx} = \lim_{\Delta x \to 0} \frac{f(x+\Delta x)-f(x)}{\Delta x}$, the definition which is used to manipulate derivatives through first principles. All ten participants were well aware of the symbolic representation of the derivative and took efforts to integrate it simultaneously to the graphical representation. After converting the coordinates into symbols, teachers then explained verbally, the method of computing the gradient of the secant line *PQ* by drawing a triangle. Few teachers clearly represented the gradient of the secant either through the ratio $\frac{rise}{run} = \frac{\Delta y}{\Delta x}$ or by $\tan\theta = \frac{\Delta y}{\Delta x}$. Following this, they switched to symbolic representation to develop two equations in order to derive an expression for $\frac{\Delta y}{\Delta x}$.

Their next step was to explain the role of limit. Some teachers switched to graphical form again to demonstrate how Δx approaches zero and teachers E, C and J drew series of secant lines (three or four lines) until *Q* approached *P* and they also used hand movements to demonstrate how secant line gradually approaches *P* until it is about to overlap with tangent at *P*. Other teachers (A, G, H, I, O) graphically and (or) verbally demonstrated how Δx approaches 0 by referring to the Δx distance marked on the *x*-axis. After incorporating limits, they finally reached the final symbolic version of the definition of derivative $\lim_{\Delta x \to 0} \frac{f(x+\Delta x)-f(x)}{\Delta x}$ provided the limit exits. While verbally explaining the concept displayed through the graphs, teachers simultaneously translated verbally and graphically presented ideas into symbols. It was also evident that majority of them moved flexibly between symbolic, verbal and graphical representation and tried to establish links between representations (see Fig. 6).

However, it was noticed that none of the participants, even the ones who were privileged to use SMART boards, took efforts in integrating computer generated diagrams to explain the main idea behind the derivative, instead used traditional static graphs to demonstrate the concept.

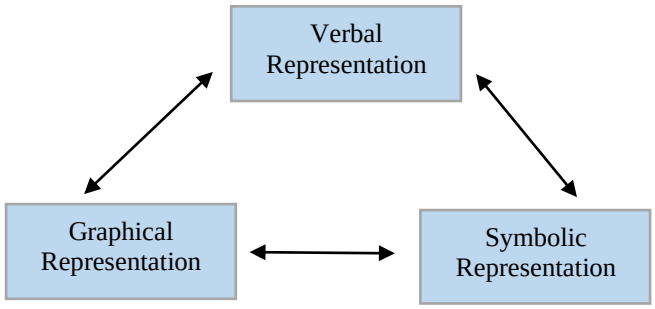

Fig. 6. Establishing links between representations

C. SCK-MJ: Mathematical Justification

SCK-MJ represents the knowledge of the teacher in providing valid mathematical justifications for actions undertaken during instruction. For the purpose of this study, we used the definition of justification outlined in [7, p.448] as "an argument that demonstrates (or refutes) the truth of a claim that uses accepted statements and mathematical forms of reasoning". Deriving the formal definition of derivative encompasses many steps that build on several mathematical concepts such as average rate of change, gradient of a secant line, the concept of limit, etc. We will outline the level of SCK of teachers in justifying five main actions/steps found in instruction namely: (1) drawing a tangent line (at *P*), (2) choosing another point (say *Q*) on the curve $y = f(x)$, (3) drawing a secant line *PQ*, (4) writing an expression for difference quotient and (5) applying limits to difference quotient.

A derivative lesson usually begins with considering the problem of defining the gradient of a curve $y = f(x)$ at a point *P* on it (or the gradient of tangent line to the curve at *P*). Students need to understand that, unlike for a straight line, gradient of a curve is not constant and therefore the gradient of a curve at a point cannot be simply computed using the general gradient formula. However, it was noticed that, all teachers (except teacher I) failed to do this comparison. In order to establish valid connections between topics, it is of paramount importance to emphasize the difference between the gradient of a linear function and a curved function. It is also important to convey that average rate of change and instantaneous rate of change are identical for linear functions and are not necessarily identical for non-linear functions.

The next common step noticed was drawing a tangent line at *P*. All teachers drew a tangent line to the curve without mentioning that it is the very line whose gradient needs to be defined. There is no way to draw the tangent without **knowing** its gradient.

Further to that, learners need to understand that the gradient of the tangent at *P* is still unknown (since they only know one point on the tangent line) which can be approximated by the gradient of the secant line *PQ* (or average rate of change). However, such reasoning was lacking in many lessons. Teachers directly plotted the second point (say *Q*) on the curve by moving Δx along the *x*-axis from *P* and then drew a line segment by connecting *Q* with the fixed-point *P*. However, except teacher C, all other teachers chose the second point *Q* without giving a valid reasoning for such action. To understand their actions, the excerpt of teacher E is given below.

Teacher E, Line 3:

> *So now I mark two points on this curve... one is P... other one is called Q…then if this point P is x…then correspondingly what will happen to the point here* [teacher locates a point on *y* axis] *...y is equal to f(x)...do you understand? This point Q is not very far from P…very close...when x is given an increment called delta x... that means when we give a very small change, it will go to point Q...is it clear?...then what are the coordinates of point Q here?..*[Contd…]

As in the above explanation, teacher E directly marked the two points *P* and *Q* on the curve $y = f(x)$, identified the coordinates of *Q* as $(x+\Delta x, y+\Delta y)$, followed by writing the difference quotient. All teachers failed to mention that the gradient of the secant line *PQ* doesn't accurately represent the gradient of the tangent at *P*, but it is just an approximation. None of them justified how this approximation gets improved as *Q* gets closer to *P* along the curve. "Approximation" is an important terminology that needs to be introduced at this point of the lesson. However, the justification for choosing *Q* closer enough to *P* was barely discussed. Teachers selected a nearby point *Q* to *P* (from Δx distance along the *x*-axis) and also stressed that Δx needs to be a very small distance, but failed to mention the reason for taking a small distance instead of a large distance.

Teacher H, Line 10:

> *Now I said that this delta x gap is a very small gap…it is very close to* x_0 *..now I make this delta x… smaller and smaller...and then I see what happens to this to the ratio of delta x over delta y when delta x becomes smaller and smaller.. What happens when it is reduced?* [Contd…]

As in the above excerpt, teacher H just mentioned "delta *x* gap is a very small gap", but he failed to mention reason for opting for a small distance delta *x*. Finally, in applying limits, most teachers mentioned that the secant line *PQ* overlaps with tangent line at *P* as delta *x* approaches zero. However, none of them explained that the gradient of the secant line *PQ* becomes a good approximation for the gradient of the tangent line at *P* as *Q* becomes close enough to *P*. More technically, as *Q* reaches *P*, the average rate of change gradually becomes a better approximation for the instantaneous rate of change. The only way to achieve this is applying the limit which can be mathematically represented as $\lim_{\Delta x \to 0} \frac{\Delta y}{\Delta x} = \lim_{\Delta x \to 0} \frac{f(x+\Delta x)-f(x)}{\Delta x}$. Apparently, many teachers missed this opportunity to point out an important application of limit.

Overall, it was revealed that majority of the teachers' mathematical work were algorithmic and those procedures were barely justified. These results are striking and indicate that many teachers had the primary intension to derive the formal definition of derivative by following a common algorithm, thereby lost the opportunity to provide conceptual understanding of the derivative. However, if the teachers elaborate "whys of what they're doing" [7, p.448], it scaffolds learning and develops life-long skills like mathematical language development, communication, critical thinking and independence. Further to the above analysis, it is also believed that teachers strictly adhering to the main guidelines outlines in the teacher guide and following the exact steps in it. This may prevent them from thinking and elaborating on the mathematical procedures. However, teachers need to be aware that teaching guides only outline the main content in the lesson and that they need to draw from their SCK in supporting ideas, justifications and reasoning.

D. SCK-ML: Mathematical Language

The final SCK component related to teaching the concept of derivative is SCK-ML which discusses the knowledge of teachers in utilizing mathematical language in instruction, focusing on vocabulary, symbols, and natural language. However, we will not particularly discuss the symbolic usage in this section as it was already being outlined under SCK-MR.

The finding revealed both positive aspects and deficiencies under SCK-ML. On the positive side, it was noticed that majority of the teachers were fairly conversant with the mathematical symbols and vocabulary and they placed a considerable attention to their language in teaching derivatives. As listed below, majority of the teachers adequately explained the new terminology pertaining to the lesson derivative.

1) *Average Rate of Change*

One out of ten teachers (teacher I) mentioned about average rate of change which is one of the most important phrases to be recalled and utilized when finding the gradient of the secant. This outcome is consistent with the fact that most teachers did not recall prior knowledge (SCK-PK) on gradient formulae for straight line nor explicitly mentioned the gradient of the secant as the average rate of change.

2) *Delta x*

Majority of the teachers adequately and repeatedly explained the meaning of Δx and Δy. Most of them used the word phrases like "a very small change", "a small distance", etc. to elaborate Δx and the evidence for such discussions are given below.

Teacher E, Line 3:

> "*When x is given delta x increment…that means* ***a very small change****…*"

Teacher G, Line 6:

> "*Generally when x changes…accordingly y changes. ..isn't that so?* ***A small change in x*** *is known as an increment in x and that denotes by delta x. ok? Therefore, delta y is the increment of y corresponding to delta x increment in x".*

3) *Difference Quotient or Increment Ratio*

Only a very few participant teachers (E, G, J and N) displayed their mathematical language fluency in introducing technical names for $\frac{\Delta y}{\Delta x}$ as *difference quotient, increment ratio or ratio between increments* while all others just read the symbolic notation as delta *y* over delta *x*.

Teacher E, Line 9:

"*So delta y means the increment in y… divided by delta x which is the increase in x... is that clear? So what do we say for this? Difference quotient... Difference quotient…*"

4) *Differential Coefficient*

In Calculus, $\frac{dy}{dx}$ is given denoted by several names. Therefore, it is important to explicitly introduce the words and their meanings, otherwise the complexity of such words would hinder understanding the overall concept of derivative. Many teachers used "first derivative" or simply "the derivative" to denote $\frac{dy}{dx}$ while few teachers used the words, "instantaneous rate of change", "derived function", "differential coefficient" to introduce the same and applied such words interchangeably in their discussions to make sure that students got familiar with the new terminology and their meanings. Excerpts of such discussions are as follows.

Teacher I, Line 10:

"*However we can take it as limit delta x goes to zero delta y over delta x. this limit zero delta y over delta x goes to zero called the* ***instantaneous rate of change***."

Teacher E, Line 17:

"*So what is defined by the* ***first differentiation*** *that is dx by dy? gradient of a curv*e"

Teacher G, Line 11:

"*Now if this limit exists… then that is defined as the* ***differential coefficient*** *or derivative of function f at x…"* [Contd..] *… "or you can call it as* ***first derivative****"*

Teacher G, L12:

"*f dash x or dfx by dx is called the derived function of f*(*x*). *Ok? we derived it from f*(*x*)...[Contd...]"

Based on the above findings, it was also evident that many teachers elicited their content knowledge on the topic specific vocabulary pertaining to the concept of derivative, critically evaluated the meaning, discussed its' usage and repeatedly used such vocabulary during instruction. Such work of teachers reflected their effort in augmenting students' mathematical lexicon.

Few flaws were also noticed from some teachers' due to slip of the tongue and use of ambiguous language with demonstrative pronouns like *this, that and these*. This hinders the precision of ideas conveyed and students can be easily misled. In such cases, teachers missed opportunities in creating mathematically rich discussions. Mathematics is a universal language, so everyone who uses it needs to adhere to standard notations, syntax and vocabulary to articulate ideas precisely. However, when the language is vague and imprecise, the overall meaning gets distorted. Most notable outcome was that teachers who exhibited stronger knowledge in other SCK components (i.e. SCK-PK, SCK-MR and SCK- MJ) also exhibited a high level of proficiency in SCK-ML. Specifically, teachers C, D, E and H exhibited their proficiency in the use of mathematical language throughout the entirety of their lessons, with minor lapses. They ensured the use of accurate phrases and vocabulary that are comprehensible to learners. The results shed light into the importance of the mathematical language in delivering complex mathematical ideas. In order to ensure error-free discussions, teachers need to stick to domain specific vocabulary, use them precisely and consistently, practice with articulating ideas and need to refrain from oversimplifying or overgeneralizing mathematical concepts through colloquial terms.

Overall, this research focused on the *unique work of teaching* to understand the current standing of A/L mathematics teachers in terms of SCK. Their unique mathematical work employed during the derivative instruction reflected several strengths of SCK that support student learning as well as deficiencies that hinder learning. Most notable finding was that a relationship was apparent in between components of SCK and if a teacher is competent in one component, he or she demonstrated proficiency in many other SCK components while the converse was also true.

While acknowledging the fact that A/L teachers deal with a tough classroom schedule and handle immense pressure for the completion of a lengthy syllabus, the pedagogical and content knowledge gaps needs to be addressed immediately for the betterment of both teachers and learners. Owing to the exam oriented teaching-learning setup, teachers tend to prefer procedural aspects than facilitating a conceptual understanding on abstract mathematical concepts. Although not statistically proven, results also demonstrated that years of experience may not always determine teacher knowledge as teachers with decades of teaching experience exhibited significant deficiencies in communicating ideas, justification and conceptual understanding. Nevertheless, professional qualification tends to predict the teacher knowledge since, despite few lapses, teachers with MSc in Mathematics Education demonstrated their proficiency in terms of many SCK components when compared to others who do not possess professional qualification in teaching. Teachers as educators are expected to strengthen the understanding of the mathematical work of teaching (or mathematics *for* teaching) to develop students' broader mathematical landscape. Educators, teachers and policy makers need to clearly distinguish the knowledge requirement of teachers to teach mathematics. It is understood that completion of undergraduate advanced mathematics modules would not suffice, instead, they need to have a deep understanding on the unique mathematical work associated to the profession of teaching.

However, to get better insights this study could have employed more participants. Owing to certain constrains imposed by schools during covid-19 pandemic, we were not able to reach the expected target of 16 participants for the derivative instruction. Further to that, few selected participants were infected hence their lesson were not observed. Another notable, but inherent limitation of this type of study is that observed lessons might have been specifically prepared for recording purposes. Consequently, the observed lesson may not reflect the true nature of their teaching. This was evident from the feedback received from some teachers who admitted that they tend to skip such introductory session on derivatives unless these sections are

directly assessed in Advanced Level examination. Hence, future studies could consider employing random classroom observations to explore the true picture of SCK during instruction.

IV. Conclusion

SCK is a specific type of subject matter content knowledge that is essential for mathematics teachers in carrying out the unique mathematical work related to teaching. Through this study, we were able to identify four distinct components of SCK in teaching the concept of the derivative namely: SCK- PK, SCK-MR, SCK- MJ and SCK-ML. Despite contextual differences, the alignment between the proposed SCK components in this study and empirical results in [3] is noteworthy. These results strengthen the applicability of MKT model (originally developed based on primary teachers in United States) to the secondary teaching in Sri Lanka with a few refinements.

It is clear that teachers are the role models in the classroom who shape the teaching-learning process. Hence, it is essential for them to know the content of subject well enough so that they could teach it to others. There focus should not be limited to "how much" content they teach, but "how well" they teach the content. In such nature, teachers cannot afford gaps in their instructions. However, the above qualitative analysis revealed various proficiencies as well as deficiencies in SCK during their practice. To address these identified gaps, it is a timely strategy to launch workshops and seminars that are tailor made to uplift necessary content knowledge required for teaching. Further to that, education policy makers need to take prompt initiatives to design mathematics content courses which are free from typical content under university mathematics courses but to capture the mathematical knowledge demands for future teachers. It was evident that teachers require necessary guidance to overcome their flaws in the subject matter knowledge. Hence, it is vital to foster collaboration among teachers, teacher educators, lecturers and other mathematics experts in knowledge within the community. Also, it was noticed that teachers who had access to such tools through smartboards utilized them solely as conventional whiteboards for writing purposes. Therefore, it is important for schools to take proactive training initiatives for teachers to optimize the use of interactive technology to facilitate teaching-learning process.

This study contributes new knowledge to the existing body of literature that focuses on exploring and developing the content knowledge of mathematics teachers and specifically in the area of SCK. While previous studies have predominantly employed Ball, Thames and Phelps's [3] MKT framework to gauge the knowledge of primary or elementary level teachers, this study extended the model to senior secondary context by examining SCK from a different perspective. Furthermore, this study extended upon the *routine tasks*, outlined in [3], that demands SCK and proposed a list of SCK components specifically tailored to assess the knowledge in teaching the concept of derivative. The development of such SCK framework serves multiple purposes including acting as a guideline to identify the SCK of teachers in a more objective manner, ensures consistency in evaluating SCK across different contexts or settings and facilitates replication of the same research with new samples of teachers from other districts in Sri Lanka to draw more comprehensive and generalized conclusions. It is worth noting that, while there is an abundance of research focusing on MKT of prospective student (teachers), limited research exists on in-service teachers. This study was able to address this gap by exploring how experienced (in-service) teachers demonstrate their knowledge in an actual classroom setting. Most importantly, to the authors' knowledge, no study has been conducted in Sri Lanka on exploring MKT of mathematics teachers. Therefore, the results of the current study provide invaluable insights into the current standing our A/L mathematics teachers in terms of their content knowledge and also the level of attention required towards developing their SCK.

Acknowledgment

This research was financially supported by the University of Jayewardenepura, Sri Lanka under the research grant No: ASP/01/RE/TEC/2021/68.

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POSTERS

2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

Mental Performance Monitoring App Using EEG and Machine Learning

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***Abstract*—Although a person can be identified physically in a task, it is difficult to determine whether that person is mentally focused on the task and it affects the efficiency of the task. For example, teachers can check whether students are paying attention by observing their expressions, but this is not a very effective method. Also, the accuracy of this method is very low. And it is also difficult to accurately and objectively measure someone's focus and concentration as it is generally known that a person's mental focus or concentration cannot be measured. If there is a way to measure this, it would help with conclusions in the fields of health and neuroscience. Using electroencephalography (EEG) and Machine Learning, we develop an app to monitor the brain's attentional activity and propose a method to accurately and objectively measure one's attention and concentration. As a result, one person can identify how another person is engaged with the tasks they are doing, i.e. their level of attention with that task. Using a dataset created by collecting 25 hours of EEG data from 5 participants with the help of a modified classical EEG headset, various common features are extracted from the raw data. As the first step, we performed the classification using a Support Vector Machine (SVM) classifier and as a next step we hope to use Deep Learning algorithm to compute and analyze the identified features to identify the feature combination that best demonstrates whether someone is paying attention to the task. This proposed method achieved almost 94% accuracy while identifying the attention level of a subject.**

Keywords—EEG, focus, machine learning, BCI, SVM

I. INTRODUCTION

Attention is the ability to keep one's cognitive process on a task at a given time, ignoring distracting or irrelevant information. All the time, neurons in the human brain are continuously active, emitting small electromagnetic waves, and these electromagnetic waves are used as electroencephalography (EEG) signals. It is feasible to use EEG signals for this, as without training, people are usually unable to control the fluctuations of their EEG signals.

Based on the frequency range, EEG signals are divided into five wave bands α, β, θ, δ and γ and these are produced as EEG signals from different regions of the brain. Because different areas of the brain produce EEG signals, cerebral electromagnetic activity is traditionally collected using the International 10-20 Electrode Placement System (10-20 System), which involves attaching electrodes to 37 locations on the scalp. This method enables monitoring of all EEG signal changes, but in practice it is extremely difficult and impractical to use this method. Since a person's emotions, mental state, and focus are controlled by different parts of the brain in the frontal region, monitoring EEG signals from this area is a successful way to determine whether someone is paying attention.

There are several wearable technology devices that allow the measurement of important health metrics of a person's body, such as heart activity, blood circulation, etc. Likewise, such a device related to the brain is yet to be invented. This project is being implemented with the aim of finding solutions to this problem by developing an application to measure human attention using EEG and Machine Learning. It will help in monitoring personal mental health and well-being as well as improving users' cognitive performance and productivity.

II. SCOPE, AIM AND OBJECTIVES

A. Scope

- Measure the user attention under the 3 categories

  In this project, the 3 levels of attention focused, unfocused and drowsiness are identified and given the appropriate output in this system

- Using an EEG band with two channels

  Multiple channels have been used for the research done so far and here we hope to do it using only 2 channels.

- Select the most appropriate ML model

  There are many machine learning models in the world and finding the most suitable model for this is another scope of this project. That is, this model is selected based on accuracy.

- Test models using university students' EEG outputs

  Another scope here is to test the selected model with live data using university students.

B. Aim

- Measuring a person's attention levels and making the results available through a personal application in such a way that the person can monitor and improve their attention and cognitive function

C. Objectives

- Preprocessing data

  Understanding the found dataset and cleaning it

- Channel selection (Feature Engineering)

Selecting the necessary features in the identified dataset and deciding the number of EEG channels required to reach the purpose of the project.

- Selecting appropriate machine learning model

  Using the EEG channels and data to test several algorithms for the Machine Learning model and choosing the most suitable algorithm

- Test mode with live data

  Test the model using the user's real-time brain data.

III. METHODOLOGY

In this project, we are using a dataset which was prepared for a previous research. İt was prepared by Çigdem Inan Acı, Murat Kaya, Yuriy Mishchenko in Turkey, for their research on **Distinguishing mental attention states of humans via an EEG-based passive BCI using machine learning methods**. They used a modified EEG headset which had 14 EEG channels (AF3, F7, F3, FC5, T7, P7, O1, O2, P8, T8, FC6, F4, F8, AF4).

The dataset consists of the results of experiments for monitoring human individuals' attention state using passive EEG BCI (Brain Computer Interface). The dataset contains the data of 34 experiments which happened during 35 - 55 mins each. In the first 10 mins, the participants have engaged in a focused task and paid special attention to the task. They have dropped their focus for the next 10 mins and then they have remained drowsy till the end of the experiment. Since the sample frequency of the used headset is 128Hz, we can divide each Matlab file as follows and label the data records,

- 'Focused': row=0 to row=128x10x60
- 'Unfocused': row=128x10x60 to row=128x20x60
- 'Drowsy': row=128x20x60 to last row

A. Data Preprocessing

(i) Initial Channels Selection

Since there were 14 EEG channels, first, we have to identify whether all the channels are useful or not. If not, we should identify which channels we should use for data preprocessing and further analysis. We plotted graphs for each channel (to represent how the amplitude has changed against time). According to the plots, we selected (F7, F3, P7, O1, O2, P8, AF4) channels as the useful channels, as we could see big amplitude changes in these plots.

(ii) Separating data of each file based on attention state

After selecting the channels, we separated each data file into 3 dictionaries based on the 3 attention states considering the row numbers. Then we could use these data dictionaries for further preprocessing and feature extraction.

(iii) High-pass filtering

For each channel and each trial, we passed the EEG data through a high-pass filter with a cutoff frequency of 0.16 Hz. In order to focus on higher-frequency activity in the EEG signals, the filtering procedure helps remove low-frequency components from the data. The filtered data is then kept in the relevant dictionaries for later analysis.

B. Feature Extraction

(i) Short-Time Fourier Transform (STFT)

We calculated the STFT on the EEG data for each channel and state (focused, unfocused, drowsy). The STFT represents the frequency content of the EEG signals in a time-varying manner. The STFT calculation is used in the next steps in order to calculate the Power Spectral Densities signals. STFT equation can be defined as follows,

$$X_{STFT}(t,\omega) = \sum_{t\prime=-\infty}^{\infty} x(t')w(t'-t)e^{-j\omega t\prime}$$

(ii) Windowing the signal

To reduce spectral leakage and increase frequency resolution, we used the 'Blackman window' function. Its smooth tapering

reduces distortions at signal segment boundaries, allowing for more precise frequency analysis and better identification of frequency components in the signal.

The Blackman window function can be defined as follows,

$$w(\hat{t}) = \left\{ \begin{array}{l} 0.42-0.5cos\frac{2\pi\hat{t}}{M-1}+0.08cos\frac{4\pi\hat{t}}{M-1}, 0\le\hat{t}\le M \\ 0, otherwise \end{array} \right\}$$

M = total amount of time points within the window

$\hat{t}$ = 0, 1, …, M−1, a discrete time-index in the window.

(iii) Calculating the Power Spectral Densities (PSD)

After calculating STFT and Windowing, we calculated the Power Spectral Densities and saved them in different dictionaries for each channel and trial. The power of a particular frequency component at a given time-frequency point is represented by each PSD value. The PSD values provide information about the relative contribution or strength of various frequency components in the signal. This information can be applied to study the dominant frequency components in each state (focused, unfocused, and drowsy) and acquire a better understanding of the signal's frequency properties. We selected PSD as the feature in the first set of experiments.

C. Training Machine Learning Models for Each Participant's Data

For our first set of experiments, we selected SVM as our ML algorithm because most of the related researches have used it as their most accurate algorithm. First, we calculated average power values and stored them in 3 separate dictionaries based on the attention states. After that, we converted the average power values into vectors for an SVM model's training. These vectors were saved in dictionaries by state (focused, unfocused, drowsy), trail name, and time-frequency bin. The vectors are then subjected to the logarithmic transformation.

Then we concatenated the data of each state of the Participant 1 and trained the SVM model. We used an RBF kernel to train the SVM model and tested its accuracy on both training and testing data.

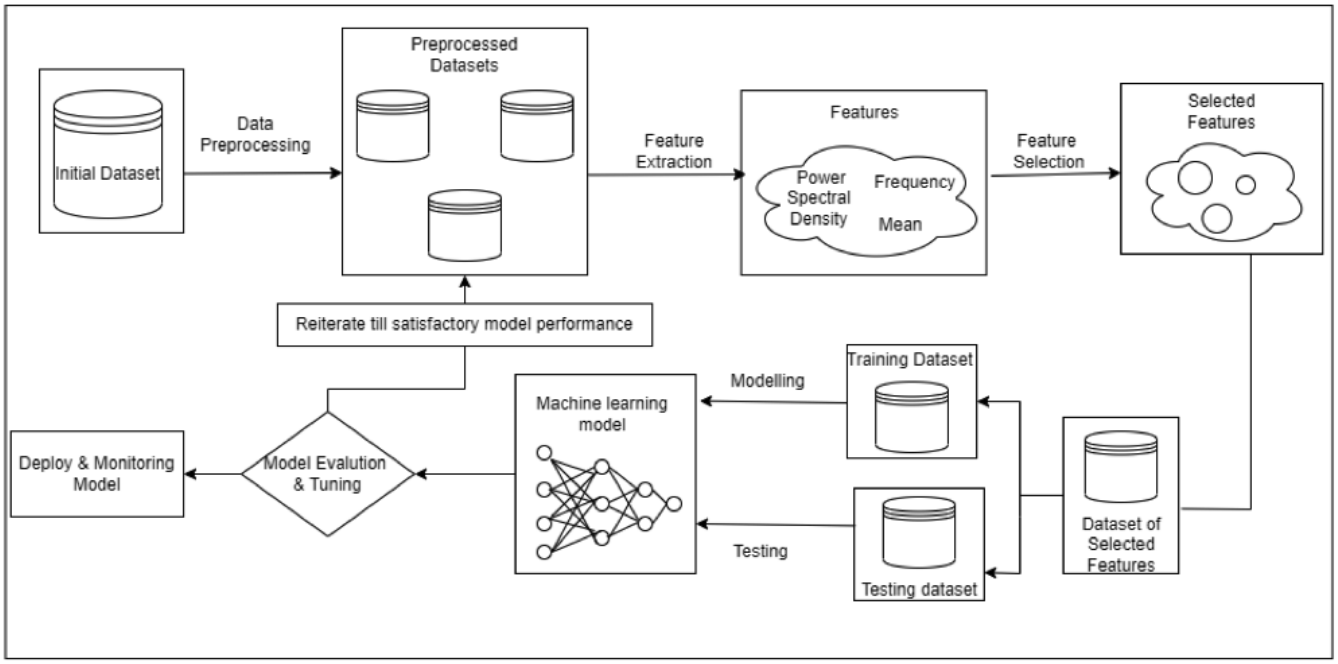

Fig. 1. Development process diagram

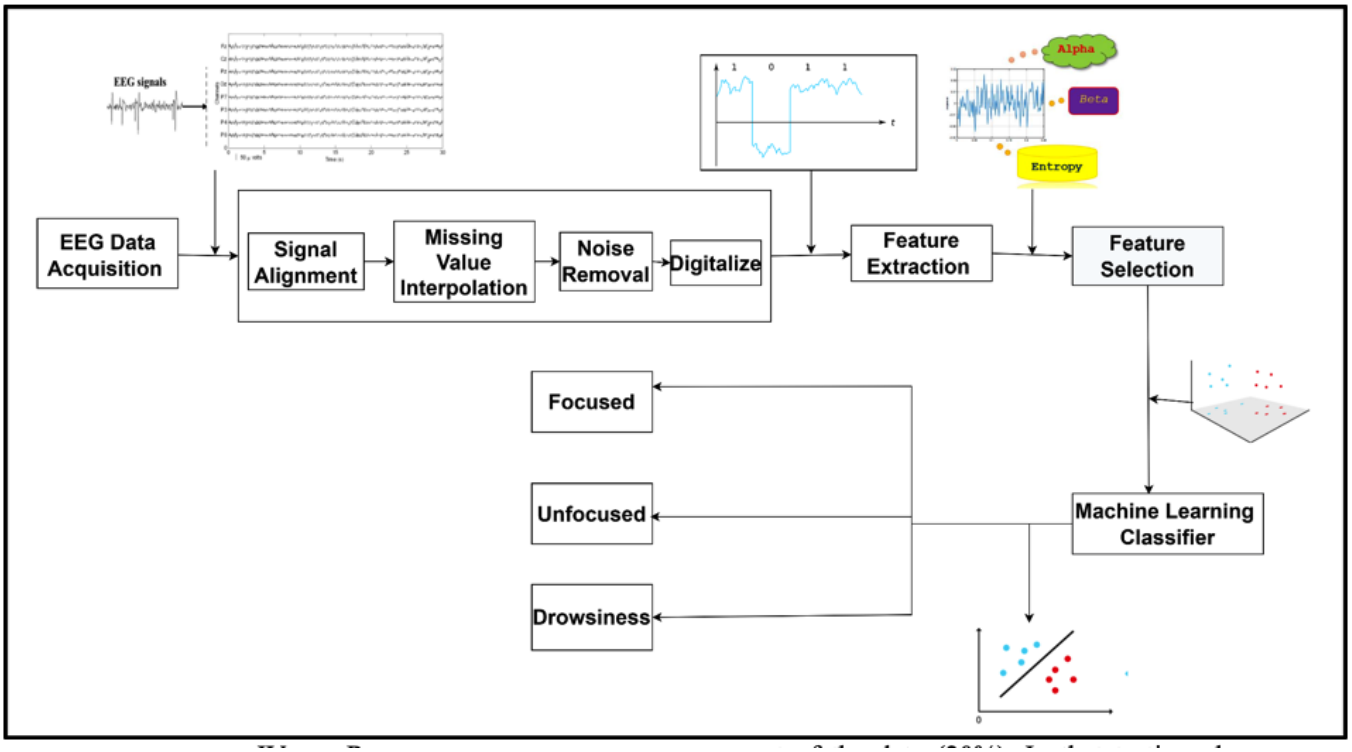

Fig. 2. Live data testing diagram

In our second major experiment, we wanted to bring a Deep Learning model as it is relatively modern when compared with SVM, and we expected we can achieve more accuracy using a Deep Learning model. After some research, we decided to develop a Recurrent Neural Network model with Long-Short Term Memory (LSTM). Using an RNN, we can effectively model EEG data which contains sequential information. LSTM has the ability of capturing temporal relationships in sequential data. Multiple LSTM layers will be used in the model, enabling it to recognize and understand complex patterns in EEG data. Moreover, end-to-end learning is made possible by LSTMs, which means that they may use raw EEG data as input and simultaneously learn feature extraction and classification. This makes the modeling process easier and frequently produces models that are more accurate and effective.

D. Testing the Trained Model Using Live Data

Here is how to test the model created in the Development Process described above using live data. Accordingly,

university students are used to extract their EEG data under suitable environmental conditions, preprocess the data and send it through the model created in the development process, and at that time, the student's state of focused, unfocused, and drowsiness will be identified and outputted.

IV. RESULTS

In the first set of experiments, we used the SVM algorithm and developed 5 distinct models using the calculated power spectral densities of each participant's data. We used 80% from each dataset for training each model and tested with the rest of the data (20%). In that testing phase, we achieved accuracies in the range of 90.4 - 96%. In the second testing phase, we tested each model using other datasets and the accuracies vary between 36.1 - 67.5

TABLE 1: ACCURACIES OF SVM MODELS

Model	Accuracy with						
	Same Dataset (0.2 split)	Subject 1 Dataset	Subject 2 Dataset	Subject 3 Dataset	Subject 4 Dataset	Subject 5 Dataset	Average
1	90.44%		67.52%	61.49%	39.06%	54.27%	55.58%
2	95.37%	62.31%		65.16%	36.32%	48.58%	53.09%
3	93.12%	54.93%	65.63%		39.20%	58.74%	54.62%
4	96.02%	37.89%	34.46%	33.45%		54.43%	40.05%
5	92.68%	37.86%	36.10%	36.72%	46.52%		39.30%

In Tab. 1, we have summarized the testing results of each SVM model and the cross-validation results with each other's data sets. In the first column, there are references to the relevant SVM models and the second column represents their testing accuracies using 20% of the relevant dataset. Cross validation test results with other participants' data are included in the next 5 columns and the last column represents the average accuracy of the relevant SVM model.

TABLE 2: MAIN SVM MODELS EVALUATION

	Recall	Precision	F1-Score
Focused	0.965	0.960	0.962
Unfocused	0.949	0.940	0.945
Drowsy	0.974	0.988	0.981

In Tab. 2, we have shown the Recall, Precision and F1-Score values of each status of the SVM models. These metrics are used to evaluate the performance of these models. The 1st column represents the status, which we are considering in this project. In the second column, there are recall values which is the true positive rate of the models. we called them sensitivity of the model. This represents the ability of the model to correctly identify instances of each state among all actual instances of the states. In the third column, there are precision values which are the accuracy of the model when it predicts a positive class. The last column represents the F1-Score, which is the harmonic mean of precision and recall. It provides a balanced measure that considers both false positives and false negatives. In the first row, there are the performance metrics for the model specially for the "Focused" state. In this status, A recall of 0.965 indicates that the model correctly identified 96.5% of the actual instances of "Focused" states. Also, A precision of 0.960 means that out of all instances predicted as "Focused," 96% were correct. And the F1-Score of 0.962 indicates a good balance between precision and recall. Accordingly, the high values for recall, precision, and F1-Score of 1st row suggest that the model is effective in correctly identifying instances of "Focused" states while minimizing false positives and false negatives. Therefore, the model appears to be reliable in detecting the targeted mental state. Considering the other rows, we can get the same conclusion for the other two states.

V. CONCLUSION

It is difficult to accurately and objectively measure someone's focus and concentration because we cannot measure a person's mental focus or concentration as we generally know. As a solution to this, suitable models are created to determine attention levels from patterns extracted from brain EEG data. It is also expected to use a two-channel EEG tape to measure user attention under 3 categories and to create models using university students. Also, one of the objectives of this machine learning model is to obtain the highest accuracy and as a result of this design, it is possible to identify how much correlation a person has with the tasks they are doing, i.e. the level of attention with that task.

The results thus obtained can be used to help the conclusions in the fields of healthcare and neuroscience. The app helps to increase and increase the role that lifestyle factors such as sleep, exercise and diet can play in maintaining optimal brain health. It can also be used by athletes looking to improve mental focus and performance, or even healthcare professionals looking to monitor and treat neurological disorders. With the potential to be used in education to monitor student attention and engagement, to optimize productivity in the workplace, and in research to study the complex functions of the brain, it is hoped that this application will lead to greater attention to brain health in society.

This project has been done by using a data set created in a previous research. Since most of the research has been done with SVM, our model was created using the SVM algorithm and the training was done using the individualized modeling method.

In this project, we hope to use more types of algorithms to check the accuracy and select the most appropriate algorithm model, and we hope to use university students to collect data under suitable environmental conditions and use that data to test the selected model. Also, we hope to bring a Deep Learning model as it is relatively modern when compared with SVM, and we expect to achieve more accuracy using a Deep Learning model.

By improving the understanding of the brain and its functions, this application that can open up new levels of performance and potential in all areas of life is a brand-new idea that has never been born in the world and the proposed plan of action is created on a logical basis.

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2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

Utilizing Climatic Data to Forecast Groundnut Yield with Artificial Neural Network in Sri Lanka

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***Abstract*—Groundnut, a major global oilseed abundantly grown in tropical areas, faces yield variations due to climatic factors. Predicting groundnut yield is essential for farmers. This research employs artificial intelligence, specifically Levenberg–Marquardt, Bayesian Regularization, and Scaled Conjugate Gradient algorithms, to predict groundnut yield. The study focuses on different districts in Sri Lanka, considering yearly, seasonal, and monthly variations in climatic factors like minimum temperature, maximum temperature, and rainfall. A three-layer neural network with 10 neurons in the hidden layer, as well as log sigmoid functions was utilized. Notably, the Levenberg–Marquardt algorithm, combined with natural logarithm transformation, yielded the highest Pearson correlation values (0.84 for training, 1.00 for validation, and 1.00 for testing) and the lowest mean squared error (2.2859×10^{-21}). K-Fold cross-validation having a K value of 5 enhanced the prediction procedure, as a result of which the mean squared error (0.3724) is smaller when applied to natural logarithm-transformed yield values. This research highlights the influence of climatic conditions in groundnut yield prediction and underscores the importance of selecting relevant factors and effective training algorithms.**

Keywords—Artificial neural network, climatic factors, groundnut, Levenberg–Marquardt algorithm, yield prediction

I. INTRODUCTION

Groundnut (*Arachis hypogaea* L.), a versatile legume crop known as peanut, holds a prominent place in global agriculture due to its substantial oil and protein content [1]. Key producers, including China, India, and Nigeria, contribute significantly to its worldwide importance. Sri Lanka, a tropical region, provides an ideal environment for groundnut cultivation, with two primary growing seasons: Yala and Maha. Yala spans from April to August, and Maha covers September to March, following local rainfall patterns [2]. In Sri Lanka, groundnuts are cultivated in the intermediate and dry zones, thriving as rain-fed crops in highland areas during the Maha season or as irrigated crops in paddy fields during the Yala season. Main groundnut cultivation areas in Sri Lanka encompass regions like Kurunegala, Ampara, Puttalama, Badulla, Ratnapura, and Moneragala with a total production of 36,947 metric tons in 2021 across 18,537 hectares [3].

Modern agricultural practices are increasingly employing sophisticated computational techniques to forecast crop yields. These techniques have led to the development of crop models and decision-making tools that are crucial for precision agriculture. These tools encompass a diverse range of methodologies, including linear regression, non-linear simulations, Support Vector Machines, Adaptive Neuro-Fuzzy Interference Systems, expert systems, data mining, Genetic Programming (GP), and Artificial Neural Networks (ANNs). The primary objective of these techniques is to accurately predict crop yields, while incorporating the impact of climate change [4]. ANNs, specifically, have exhibited remarkable proficiency in addressing intricate agricultural dilemmas such as crop disease identification, harvest automation, and product quality evaluation [5].

Inspired by the interconnected and nonlinear architecture of the human brain, neural networks create an extensive, distributed system for processing information. This approach was initially modeled after the intricate organization of the central nervous system. These networks, which are formed up of interconnected nonlinear computing units, mimic the intricate processing capabilities of the brain of human, facilitating intricate information processing. Their adaptability makes ANNs a powerful alternative to linear models, as they possess the capability to approximate a wide range of mathematical functions with sufficient data and computational resources. When constructing neural network models, three training algorithms are commonly used: Levenberg–Marquardt (LM), Bayesian Regularization (BR), and Scaled Conjugate Gradient (SCG). LM excels across various domains, outperforming basic gradient descent techniques and other methods based on conjugate gradients [6]. BR is a regularization technique employed with gradient-based solvers to prevent overfitting by constraining synaptic weightings in relation to the sum of squared errors or mean squared errors (MSE). SCG, a supervised learning approach for network-based systems, widely addresses large-scale problems. These algorithms optimize the neural

network model's training process to enhance its performance.

Temperature and rainfall fluctuations notably affect crop development across diverse regions, underscoring the importance of understanding regional climate variables while managing agricultural activity. Rising temperatures have been identified as a significant factor impacting crop yields. Extensive research has explored this phenomenon using advanced modeling techniques. In the Sri Lankan context, this research takes the lead in investigating the correlation between climatic variables specifically, rainfall and temperature data and the production yield of groundnuts. Simultaneously, it investigates the optimal training algorithm for ANN models.

II. Methodology

In this study, groundnut yield data were gathered from the Department of Census and Statistics in Sri Lanka, covering several districts including Puttalam, Badulla, Anuradhapura, Kurunegala, and Hambantota. Climatic data, comprising monthly and seasonal parameters like rainfall (mm), minimum and maximum temperature (°C), were sourced from official repositories, specifically the Department of Meteorology in Sri Lanka, for these respective districts. The data covered a substantial period, spanning from 1990 to 2018.

The primary objective of this study was to forecast groundnut yield by leveraging climatic factors through the application of two distinct methods (Method 1 and Method 2) across four different scenarios (Scenarios 1, 2, 3, and 4). Validation of the outcomes derived from the ANN was conducted using K-fold cross-validation. Equation (1) encapsulates the mathematical representation of the intricate nonlinear correlation observed in this context.

$$\text{Groundnut Yield} = \phi\ (\text{Rainfall}, \text{Temperature}_{min}, \text{Temperature}_{max}) \quad (1)$$

Method 1 involved the utilization of a three-layer neural network consisting 10 neurons within the hidden layer, incorporating the sigmoid activation function. Method 2 consisted a neural network structure from the neural network toolbox, characterized by a three-layer configuration, housing a solitary hidden layer comprising 10 neurons and employing the log sigmoid activation function.

At the outset, the model incorporated seasonal data encompassing both Yala and Maha seasons, involving variables such as Yield (Maha, Yala), Rainfall(Yala, Maha), Minimum Temperature(Yala, Maha), and Maximum Temperature(Maha, Yala) specific to the Anuradhapura district within Scenario 1. Under Scenario 2, the approach solely utilized the data which were taken from Maha season pertinent to Anuradhapura district, encompassing detailed monthly climatic information. In that scenario, the cumulative monthly rainfall and the minimum and maximum temperatures of each month were considered within the Maha season timeframe. Scenario 3 involved the aggregation of annual yields from both Yala and Maha seasons within Anuradhapura district, integrating monthly climatic data for analysis. In that scenario, the cumulative monthly rainfall and the minimum and maximum temperatures of each month were considered within the one year timeframe. Scenario 4 employed the natural logarithm of Maha season yield along with monthly Maha season climatic data, as shown in Equation 2. In that scenario also, the cumulative monthly rainfall and the minimum and maximum temperatures of each month were considered within the Maha season timeframe.

$$\ln (\text{Groundnut Yield}) = \phi\ (\text{Rainfall}, \text{Temperature}_{min}, \text{Temperature}_{max}) \quad (2)$$

MATLAB (version 9.6-R2019a) served as the platform for constructing the ANN architectures employed in predicting the yield of groundnut. In Method 1, LM algorithm performed well in Scenario 1, and thus, it was used for Scenarios 2, 3, and 4, with Scenario 4 yielding the best results.

In Method 2, similar training algorithms were applied. The LM algorithm performed well in Scenario 1, and was subsequently used for Scenarios 2, 3, and 4, with Scenario 4 as the most advantageous and optimal among the options. Ultimately, K-Fold cross-validation effectively corroborated the correlation between the yield of groundnut and climatic factors across Scenarios 1 to 4.

III. Results

A. Results Achieved with Method 1

Table 1 exhibits the groundnut yield outcomes recorded in Anuradhapura for Yala and Maha seasons, with fluctuations of climatic factors across three distinct training optimization algorithms. LM algorithm showcased superior performance compared to BR and SCG algorithms, displaying notably higher Pearson Correlation Coefficient (r) values across training, validation, testing, and overall data points. Nevertheless, BR resulted in a negative value of -0.13 for testing, whereas SCG showed -0.51 for validation and -0.10 for testing. Furthermore, the MSE values for validation were lower in the LM algorithm as opposed to those observed in the SCG method.

TABLE I. MODEL ACCURACY IN SCENARIO 1, ANURADHAPURA DISTRICT, METHOD 1

Model	**r**				**Validation MSE (kg/ha)**
	Training	***Validation***	***Testing***	***All data points***	
LM	0.49	0.22	0.32	0.44	144567
BR	0.37	NA	-0.13	0.32	NA
SCG	0.18	-0.51	-0.1	0.05	281224

Based on the results, the LM algorithm demonstrated higher r values and lower MSE values, signifying a strong correlation with predicted values and heightened predictive accuracy. Following the selection of the LM algorithm based on these findings, it was utilized for scenarios 2, 3, and 4 as detailed in Tab. 2

TABLE II. EVALUATING LM MODEL ACCURACY IN SCENARIOS 1–4 WITH METHOD 1

Models	r				Training MSE (kg/ha)
	Training	*Validation*	*Testing*	*All data points*	
LM	0.45	0.37	0.19	0.33	211778
BR	0.36	0.09	0.22	0.27	383711
SCG	-0.01	0.20	-0.07	-0.03	253457

According to the results, Scenario 4 under Method 1 demonstrates higher r values and the lowest validation MSE, indicating a robust correlation with predicted values and enhanced accuracy.

B. Results Achieved with Method 2

Table 3 displays the results of groundnut yield in the Anuradhapura district for both of the Yala and Maha seasons, emphasizing differences in climatic factors among the three training optimization algorithms. The LM algorithm consistently outperformed BR and SCG in terms of r-squared values across training, validation, and all data points. The LM algorithm also exhibited lower validation MSE values compared to BR and SCG. This suggests that the LM algorithm is better able to capture the underlying relationships between groundnut yield and climatic factors.

TABLE III. THE ACCURACY ACCORDING TO THE SCENARIO 1, IN ANURADHAPURA DISTRICT, METHOD 1

Scenario	r				Validation MSE (kg/ha)
	Training	*Validation*	*Testing*	*All data points*	
2	0.10	0.77	0.99	0.30	82394
3	0.99	0.78	0.69	0.77	535601
4	0.84	1.00	1.00	0.87	2.2859×10^{-21}

The outcomes highlight that within Method 2, the LM algorithm demonstrated superior r values and lower MSE values, indicating a robust correlation with predicted values and enhanced predictive accuracy. After selecting the LM algorithm, it was utilized for scenarios 2, 3, and 4 (Tab. 4).

TABLE IV. EVALUATION ACCURACY OF LM MODEL ACCOURDING TO THE SCENARIOS 2–4 UNDER METHOD 2

Scenario	K value	Best Model	MSE
1	5	Robust Linear	$1.8071x10^5$
2	5	Linear SVM	$1.3371x10^5$
3	5	Linear SVM	$2.7491x10^5$
4	5	Medium Gaussian SVM	0.37245

According to the results, Scenario 4 under Method 2 demonstrates higher r values and the lowest validation MSE (2.2859×10^{-21}), indicating a robust correlation with predicted values and enhanced accuracy.

C. Results Achieved with K-Fold Cross-Validation

Due to the constraints posed by limited data, K-fold cross-validation was utilized for Scenarios 1 to 4, as depicted in Table 5.

TABLE V. MSE VALUES AND BEST-FIT MODELS FOR CROSS-VALIDATION IN SCENARIOS 1-4

Scenario	Training	Validation	Test	All data points	Validation MSE (kg/ha)
1	0.49	0.22	0.32	0.44	144567
2	0.72	-0.6	0.78	0.46	860540
3	0.82	0.91	0.95	0.7	410730
4	0.95	0.98	0.93	0.86	0.4993

According to the outcomes derived from K-fold cross-validation analysis, it is notable that Scenario 4 consistently exhibited the most accurate predictive performance. This conclusion is supported by its exceptionally low MSE value, specifically registering at an impressive 0.37245. This underscores the superior predictive capability of Scenario 4 compared to the other scenarios.

IV. CONCLUSION

The results indicate that the LM training optimization algorithm consistently surpasses BR and SCG, as well as demonstrating superior r values and relatively lower MSE values across both Method 1 and Method 2. The LM training algorithm exhibits exceptional r values across various aspects of the analysis. The comparative assessment of training algorithms illustrates LM's proficiency in capturing associations between environmental factors and the groundnut yield converted to natural logarithms in both Method 1 and Method 2. In Scenario 4, the application of natural logarithm transformation narrows the range of yield data, resulting in improved outcomes characterized by higher r values and reduced MSE values. The LM algorithm's optimization strategies, combining the steepest descent method and the Gauss–Newton method, significantly contribute to its efficiency and quicker convergence. In Scenario 4, Method 2, utilizing the log sigmoid function for the neurons of ANN, outperforms Method 1. K-Fold cross-validation across different scenarios consistently supports Scenario 4 as the most accurate, demonstrating its compatibility with the LM algorithm in both Method 1 and Method 2. In this context, the LM training algorithm, with its high r values, low MSE values, and rapid convergence, proves to be the most effective. These observations underscore the importance of selecting the appropriate training algorithm, considering factor expansion and transformations to enhance predictive capabilities. They also highlight the potential effectiveness of the LM algorithm, especially when combined with sigmoid and log sigmoid activation functions in distinct methods. The use of K-Fold cross-validation further consolidates and substantiates these findings.

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2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

Greenhouse Insect Pest Detection Using Computer Vision

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***Abstract*—Due to the closed environment, greenhouse agriculture is prone to rapid insect and disease outbreaks, unlike traditional agricultural approaches. However, due to the commitment to organic farming techniques, the use of pesticides for insect eradication is not possible in most greenhouses. Thus, this research intends to provide an early pest detection system by applying image recognition technology that surpasses the existing systems. The study attempts to evaluate two methodologies to determine the most effective approach for the system.**

Keywords—Greenhouse, image recognition technology, pest, early pest detection, pesticides

I. INTRODUCTION

Changes in the seasonal cycle have made outdoor farming more challenging. As per Food and Agriculture Organization (FAO) data published in 2016, if the current situation of GHG emissions and climate change continues, then by the year 2100 there will be a decline in the production of major cereal crops (20–45% in maize yields, 5–50% in wheat, and 20–30% in rice) [1]. Moreover, due to the expanding human population, shrinking cultivable land, and water supplies, there is an urgent need to optimize food production from limited land and water sources. Protected agriculture, especially through greenhouse farming, is one method being used to deal with these problems. Greenhouse crop cultivation demands a great deal of attention. Over the past few decades, it has shown immense potential and has been successfully adopted for cultivating vegetable crops. In the recent past, there has been a tremendous increase in the area under protected cultivation (around 20 million hectares of area all over the world) [2].

One of the major problems in greenhouse farming is the presence of pests. In India, the yield loss due to various insect pests ranged from 30% to 40% among different vegetable crops [3]. Recently, Sri Lanka has experienced some major insect outbreaks, inflicting considerable economic losses. Most of the time, mistakes committed by farmers and the lack of quality in the infrastructure can lead to extensive insect threats within a greenhouse. Closed environments like greenhouses are prone to the rapid spread of pests, insects, and diseases compared to a regular agricultural field. Capsicum, chili, cucumber, tomato, and brinjal are the main crops grown in protected environments. The production of these crops is greatly influenced by insect pests [4]. In capsicum, whitefly caused 13.60% yield loss, whereas on cucumber plants, yield loss was approximately 26%. Moreover, whitefly caused a 54% yield loss in okra plants. The most frequent damage insect pests cause is due to the hundreds of plant viruses that they are able to transmit. The development of the whitefly was seen higher on eggplant and cucumber, followed by tomato [2]. Given the trend towards organic practices, the use of pesticides is no longer a practical option for most greenhouse producers. Integrated pest management systems have been widely applied in agricultural fields to minimize the use of pesticides and yield losses. In most situations, pest populations are identified and determined by physically counting the insect pests attached to sticky paper traps. This old approach is inefficient and exceedingly time-consuming. Furthermore, the global agricultural workforce is predicted to decline by 30% between 2017 and 2030 due to the availability of more lucrative job opportunities [5]. Given these underlying challenges linked with identifying and counting insect pests in the greenhouse, an autonomous pest detection technique is crucial to the modern agricultural business. Experimental results showed that the order of best strategies for virus suppression was integrated management (73%), biological control (58%), and chemical control (44%) [5]. Therefore, this project aims to propose a computer vision-based method to replace the manual pest detection task. Early detection of insect pest outbreaks is vital for farmers to take appropriate steps for the protection of crops. The whitefly is the major insect that is expected to be identified in this research project.

To the best of the author's knowledge, 2/3 of the research related to the identification of insect pests using modern technology uses image processing technology. Modern machine learning approaches are not common in pest detection when compared to image processing approaches. Mainly, the U-Net is used in medical image segmentation tasks. Therefore, this research aims to compare the performance of pure image processing with a modern machine learning-based system for pest detection in greenhouses.

II. METHODOLOGY

A. Research Methods

The image recognition part of this research is conducted using two main methodologies.

a) Image Processing using Python

b) U-Net in Python

First, images taken from the dataset are put in as the input for both systems, and then the output results of the systems are examined. Comparing both outputs and their accuracy and efficiency, the appropriate system is expected to be presented as the image recognition technique of the greenhouse pest detection system.

a) Image Processing Using Python

This image processing system was coded in Python using OpenCV2 as the library. The platform that is used to run the code is Google Colab. Use OpenCV2 as the library because it contains a large number of functions and algorithms for image processing and object detection tasks. Also, it supports numerous programming languages. Also, it has a strong community of users and developers, contributing to its constant improvement and maintenance. The first step was turning the picture into a grayscale image. Then it was transformed into a threshold picture and set the threshold value. The contour list was taken after that, and using that, insects were labeled using a red rectangle, and the number of labels was counted to get the number of insects in an image.

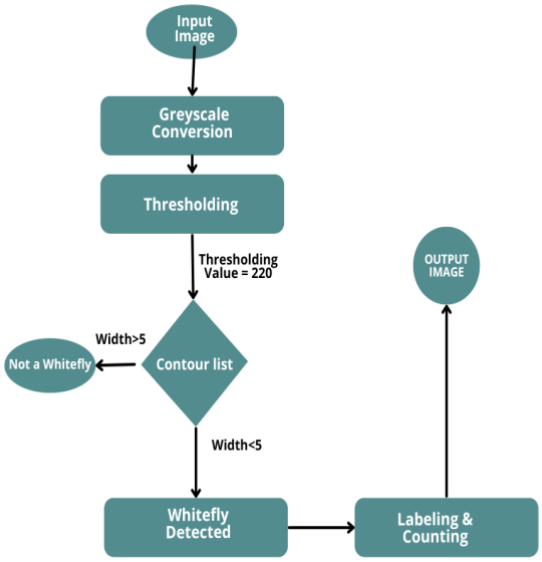

Fig. 1. Image processing method flowchart

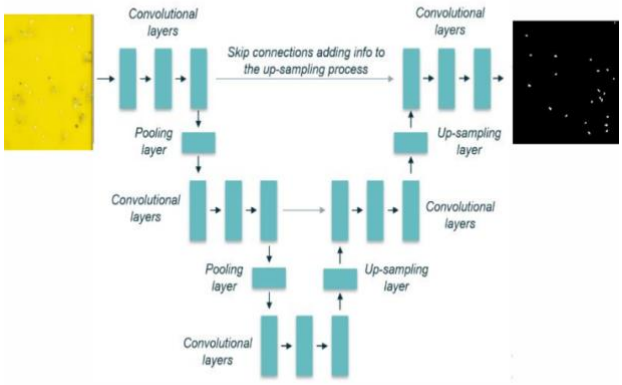

Fig. 2. Basic structure of the U-net model

The stages for pest detection on the sticky trap images using image processing are presented in the flow chart given below.

b) U-Net in Python

The U-Net architecture (Fig. 2) is a convolutional neural network (CNN) architecture that is often used for image segmentation tasks. The U-Net architecture was created to segment pictures with pixel-level precision. This design is notably employed in biological image analysis. In this procedure, resized photos of the sample dataset will be used as inputs. Following is the architecture of the U-Net model.

The U-Net model is comprised of an encoder and a decoder. The encoder is used to extract features from the input picture, and the decoder is used to upsample while concatenating the features and generating the final output. The encoder and decoder are symmetrical and connected by skip connections between them. The encoder and decoder are made up of a sequence of repeated 3×3 convolutional layers at each of the stages. After the convolutional layer, the ReLU activation function is used. The encoder is conducting the down-sampling, and the decoder is doing the up-sampling procedures. After segmenting the picture, a Python code will be used to count the number of insects in each segmented image. In this research, the U-Net model was coded using Python with Tensorflow as the library. Google Colab is used as the running platform for the U-Net model. Tensorflow is used as the library because it is widely known as a deep learning library, and most recent researches done in U-Net also used Tensorflow as the library.

B. *Data Collection*

The sample data set used in this research was published by Wageningen University & Research, Netherlands (Fig. 1). The dataset is available online at the 4TU Center for Research Data *[7]*.

Fig. 3. A zoom-in image from the sample dataset

III. Results and Discussion

A. *Image Processing Using Python*

In this method, the data set consisting of sticky trap images was used as the input. This method consists of three major parts. Grayscale conversion was done as the first step (Fig. 4).

In the second step, the image was turned into a threshold image, and the threshold value was taken as 220 (Fig. 5). In the third step, a contour list was taken. Using that contour list,

a red rectangle was created around the insect. To create the rectangle, the accepted width was taken as 5 (W<5) (Fig. 6).

In this method, whitefly is the target pest that is expected to be identified. This image processing technique has a very high level of precision. A few outcomes from the method and their accuracy have been provided in the following table (TABLE I). Overall, the accuracy of this technique fluctuates between 70% and 90%.

1) Grayscale Conversion

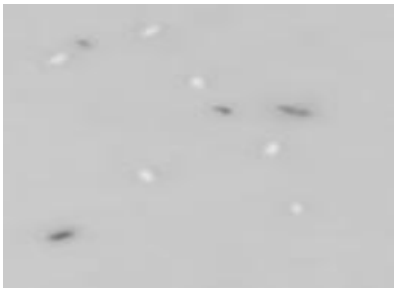

Fig. 4. Output after the Grayscale conversion

2) Thresholding

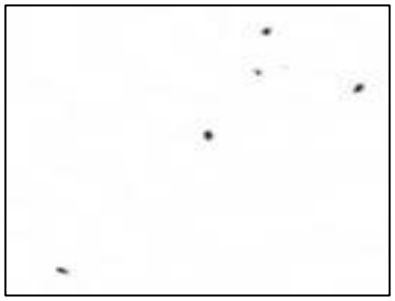

Fig. 5. Output after the Thresholding

3) Output Image

Fig. 6. Output Image of the Image Processing

TABLE 1. RESULTS OF WHITEFLY DETECTION

Image No	Whitefly in an image		
	Detected No	Actual No	Accuracy of the Method (%)
1	133	159	836
2	69	88	78.4
3	189	234	80.7
4	49	65	75.3
5	43	53	81.1
6	16	19	84.2
7	8	9	88.8
8	13	16	81.2
9	18	23	78.2
10	9	12	75.0

B. U-Net using Python

The data set was divided into training, validation, and testing according to the ratio of 70:20:10. Then, the training data set was manually annotated to create the corresponding mask image data set. In the input stage, each image in the dataset and masked set was cropped to 256×256 patches because it is easy to train the model with small images.

Fig. 7. Zoom-in image of an input testing image

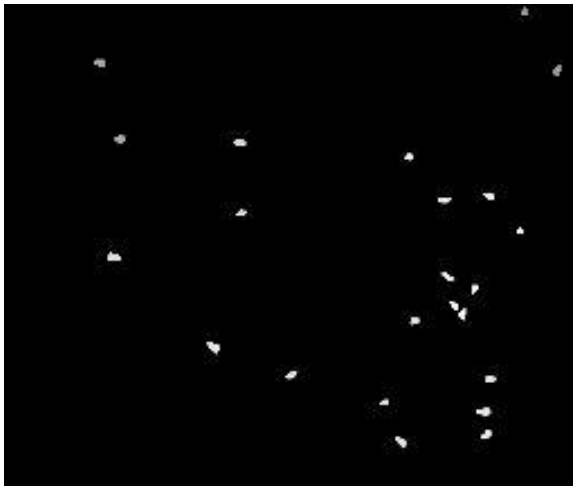

Fig. 8. Zoom-in image of an image segmentation output

This U-Net model shows a good amount of accuracy when tested with the dataset. Intersection over Union is an evaluation metric that is used to measure the accuracy of an object detection model on a dataset. For this model, the IoU score is 81%. This is a good amount for a semantic segmentation model.

IV. Conclusion

This research is about developing a computer vision-based, accurate, automated system for the identification of greenhouse insect pests. Two approaches of computer vision, Image processing and U-Net (deep learning) are used as the proposed methodologies in this research project. At the end of the research, two methodologies were evaluated, mainly considering their accuracy, efficiency, and ease of use. From the results of both methodologies, both are suitable for use in computer vision-based pest detection systems. Both testing techniques are invariant to the rotation factor. Traditional image processing method shows low accuracy of pest detection for some of the input images. This error can be minimized by improving the image quality and using a different color of sticky trap in the data collection process. This image processing method can be developed to detect other types of insects (multiclass insect detection). The U-Net model shows satisfying accuracy, which is greater than the image processing method's overall accuracy. The accuracy of the U-Net model can be improved by using more training datasets. Furthermore, the accuracy and efficiency of the model can be improved by reducing the human error that occurs in the training dataset annotation process. Multiclass segmentation can also be added to this model to detect other kinds of insects that damage greenhouse crops.

Through this research, greenhouse pest detection becomes much easier for farmers who are new to greenhouse farming and have little expertise about greenhouse pests. Also, this research is expected to benefit existing farmers who employ a large amount of labor and resources for the identification of insect pests in greenhouses. When comparing the accuracy and results of both methodologies, U-Net image segmentation is more suitable for the early pest detection system. This research is done basically to discover and detect the whitefly insect, which is typically available in a greenhouse environment. Research can be extended by developing it to detect more pest species and by developing it for use in outdoor farming as well. In further development, this research can be integrated with wireless communication methods to develop a real-time pest monitoring and alerting system for farmers.

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2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

An Automated System to Classify the Maturity Status of Papaya Fruits Based on Transfer Learning Approach

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***Abstract*—Papaya (*Carica papaya*) is a delicious fruit with high medicinal and nutritional value, making it in high demand both as a fruit itself and in various papaya-based products, *viz*., beverages, pharmaceuticals, and jam. Hence, increasing the volume and the quality of those products is essential. One of the main barriers to increasing the productivity of papaya-based products and papaya packaging is sorting out the fruit manually according to its maturity status. Manual sorting is highly time-consuming and expensive. One of the best solutions to overcome this issue is the automation of the process using machine learning (ML) techniques. In this project, an efficient conveyor system has been developed with the support of image processing and a transfer learning approach. For training a CNN, a dataset consisting of 1109 images of over-mature papayas, 1054 images of mature papayas, and 1367 images of immature papayas were used. Models of EfficientNetV2B1, MobileNetV3, ResNetRS50, and VGG19 were used to train CNN. Among these models, MobileNetV3 exhibited the best performance, with an accuracy of 100% within 10 epochs and a loss of 0.006%. EfficientNetV2B1 also exhibited 100% accuracy. However, the loss was 0.31%. ResNetRS50 reached 100% accuracy, and the loss was identified as 0.54%. The lowest performance was exhibited by VGG19. Though its accuracy reached 100% within 30 epochs, the loss was 151.37%. Therefore, MobileNetV3 was identified as the most accurate model to classify the maturity status of papaya fruits.**

Keywords—Automated system, image processing, machine learning, maturity status, papaya fruit, transfer learning approach

I. INTRODUCTION

Papaya (*Carica papaya*) is a delicious fruit that contains a high nutritive and medicinal value. It has been proven that papaya can reduce heart disease threats and prevent the oxidation of cholesterol since it contains antioxidants like vitamin A, vitamin C, and vitamin E [1]. Fiber in the fruit also helps to reduce cholesterol, thereby decreasing the threat of heart problems. Papaya not only decreases heart disease but also helps with digestion and decreases inflammation; hence, it contains papain and chymopapain enzymes. Moreover, vitamin C content boosts the immune system. As a tropical fruit that grows in Asian countries, a wide range of varieties, including Guinea Gold Papaya, Hawaiian Sunrise Papaya, Hawaiian Sunset Papaya, Hortus Gold Papaya, Kamiya Papaya, Kapoho Papaya, Oak Leaved Papaya, Peterson Papaya, etc., can be identified [2, 3]. In Sri Lanka, there are inherited varieties like Red Lady, Horana Hybrid, and Rathna. Generally, there is a yield of 60-100 metric tons per hectare per year from these verities in Sri Lanka. Due to its medicinal value and high yield throughout the year, papaya has a great global market value and industrial value as a fruit as well as processed products including beverages, jam, cordial products, chewing gum, soap, toothpaste, pharmaceuticals, and tanning [2, 3].

Due to these reasons, it is crucial to promote papaya cultivation, foster innovation in papaya-based products, and facilitate the exportation of both papaya fruit and papaya-derived processed goods. To dominate the local and international market for papaya, it is essential to increase the efficiency of production and maintain a high-quality margin. Therefore, an automated system for maturity status identification of papaya based on machine learning can play a significant role. Automating a sorting process can maintain quality and increase the efficiency of the process more than manual sorting since the automated system can work for 24 hours without taking a break [4]. Also, it can play a crucial role in mitigating the occurrence of damages during a manual sorting process. By reducing unnecessary labourer costs, manufacturers can produce quality products at the lowest possible prices. Therefore, it is a clear fact that this type of automated system can play a vital role when competing in the international market as well as the local market by maintaining high quality and high production efficiency. Due to these reasons, this project focuses on implementing a

machine-learning-based papaya classification system according to their maturity status.

At present, in the manufacturing industry, artificial intelligence (AI) is used almost everywhere, owing to its capacity to process a vast amount of data, provide accurate predictions, and have self-learning abilities [4]. Mainly, fruit preprocessing industries use machine learning (ML, a subcategory of AI technology) base systems to sort out different fruits, classify fruits according to their maturity status, identify damaged and deformed fruits, etc. This project uses supervised learning: convolutional neural networks (CNN), since CNNs are best for solving computer vision-related problems and have higher feature extraction compatibility. Furthermore, the transfer learning (using a pre-trained model to solve the different problems) approach is used in the project.

II. Methodology

The methodology can be divided into three main stages: training and fine-tuning the ML algorithm, implementation of the prototype conveyor system for sorting papaya, and implementation of the graphical user interface (GUI). The overall workflow of the system is shown in Fig. 2.

A. Training and fine-tuning the ML Algorithm

1). Data Collection

For collecting images of papaya in order to create a training dataset, an A4tech PK-910H web camera was used. This full HD camera boasts a resolution of 1920 × 1080 pixels and operates at a frame rate of 30 fps. In order to prevent disturbance of exterior light sources a cover and a stand with a height of 0.5 m were occupied. Inside the cover, two bar lights with a temperature of 5500 K were employed as the primary light source. The front lighting method was adopted, providing an illuminance level of 170 lux inside the cover.

2). Data Categorization

When training a CNN using a supervised learning method, the training data set should be divided into intended categories. During the learning process, CNN adjusts its weights according to similar patterns in the given categories [5]. Accordingly, in this project, the collected papaya image data set has been manually divided into three categories and put into three files under the labels 0, 1, and 2. File “0” contained the immature papaya category; file “1” contained the mature papaya category, and file “2” contained the overly mature papaya category. This categorization was done based on the outer skin color of the papaya fruit, as shown in Fig. 1.

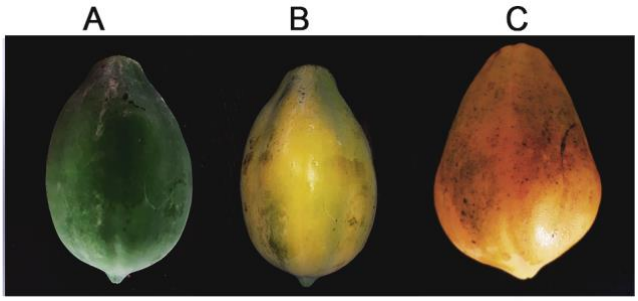

Fig. 1. Sample papaya fruit images collected. (A) Immature, (B) Mature, and (C) Over-mature.

3). Data Cleaning

In the collected data set, there was depraved data, or, in other words, corrupted pictures like blurred pictures, pictures with unwanted background noise (like objects in the background and light spots), and images with imprecise sizes. When training the neural network, this kind of depraved (or bad) data adversely affects the accuracy of the predictions since those images cause unnecessary changes in weights. Therefore, the depraved data was removed to obtain better performances. Also, the image categories were revisited, and mismatched images were removed. For instance, there can be images of mature papayas in the immature category or in the over-mature category, which can adversely affect the accuracy of the model. Further, the data set was revisited several times, and confusing images like images with bad lighting and images with a few or a portion of papaya instead of one were cleaned in order to enhance the accuracy of the model.

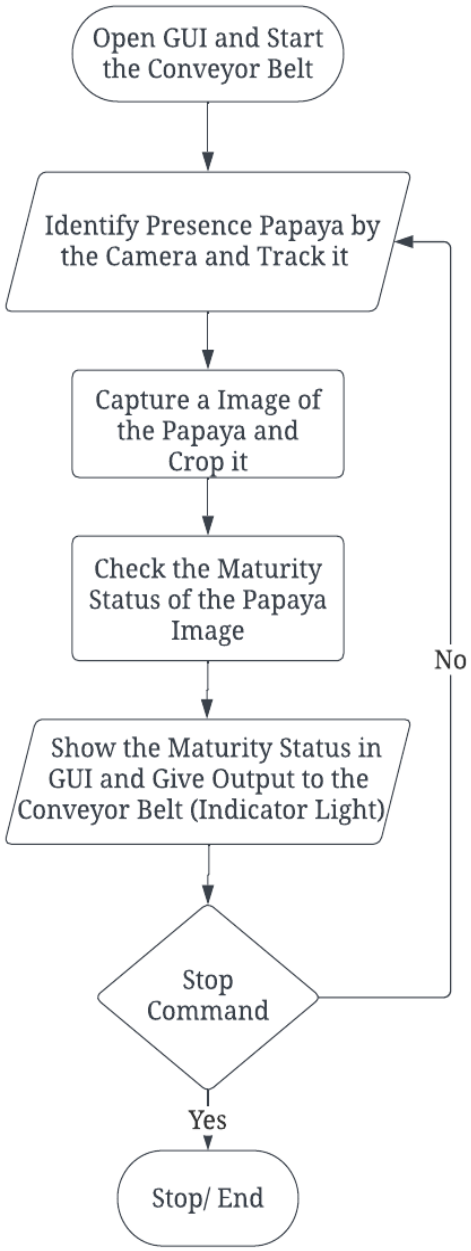

Fig. 2. Workflow of the system

4). Implementation of ML Algorithm

Python was chosen as the programming language for implementing the ML algorithm since it is a high-level language with flexibility and simplicity. The transfer learning approach, which uses pre-trained CNN models for retraining to find a solution to the intended problem, has been used. The pre-trained models EfficientNetV2B1, MobileNetV3, ResNetRS50, and VGG19 were considered [6]. The final layer of those pre-trained CNN models was changed to obtain the intended output, which has three (03) categories (immature, mature, and over-mature). Thresholding and background subtraction methods were used to identify the presence of papaya fruit on the conveyor belt. In the implemented system, as the papaya fruit moves along the conveyor belt, the camera captures images containing papaya fruit, which can be detected using threshold values as shown in Fig. 3.

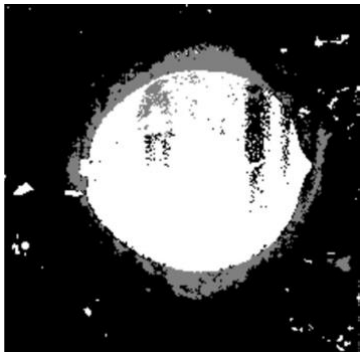

Fig. 3. Background subtraction

B. *Implementation of the Prototype Conveyer System.*

To run the conveyor belt, the stepper motor (NEMA17 17HS4401), which has a holding torque of 280 mN/m, was used, and the TB6600 Arduino stepper motor driver was used to control them. Overall, the combination of a NEMA17 stepper motor and a TB6600 Arduino stepper motor driver is a powerful and reliable solution for applications where precise positioning and control are important. The A4tech PK-910H web camera was used for capturing the images. It has a high-definition resolution of up to 1920 × 1080 pixels. It has a wide viewing angle of up to 80 degrees, allowing it to capture a large area in front of it. Further, for implementing the main unit and serial communication, an Arduino Uno board based on the ATmega328p microcontroller was used. Finally, three (03) indicator lights were occupied in the hardware setup to indicate the maturity status of the papaya fruit, as shown in Fig. 4.

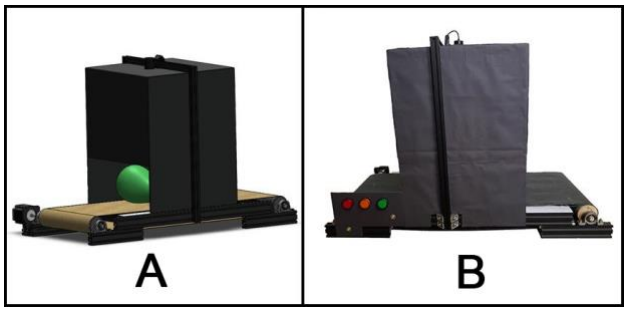

Fig. 4. (A) 3D Model of the conveyor belt system and (B) Conveyor belt system built for the project.

C. Graphical User Interface (GUI)

Tkinter is a Python library that is used for creating graphical user interfaces (GUIs). It is a standard GUI library for Python and is included with most Python installations. Tkinter provides a set of tools for building and customizing graphical interfaces, including buttons, labels, text boxes, and other widgets. The implemented GUI is shown in Fig. 5.

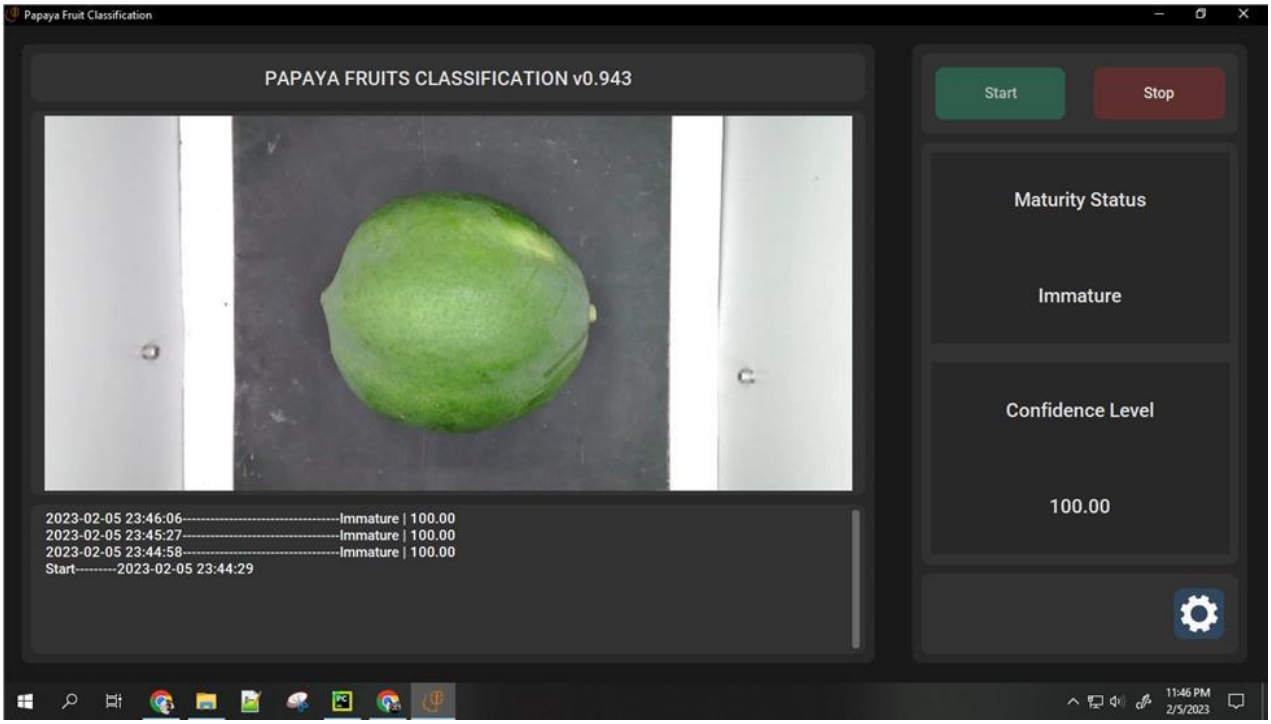

Fig. 5. Graphical user interface (GUI).

III. Results and Discussion

This section discusses different results obtained by training different CNN models. Since the transfer learning approach was used for this project, four (04) different pre-trained models: EfficientNetV2B1, MobileNetV3, ResNetRS50, and VGG19 were considered. An MSI laptop with the following specifications: an i7 9th generation processor, 2.60 GHz, 8GB of RAM, and an NVIDIA GTX 1650 4GB GDDR5 graphic card was used to train the models. The same dataset was used to train all four (04) models, and this data set was divided into three (03) subsections: training, validation, and testing. Tab. 1 illustrates the image distribution among the subsections.

Table I. Collection of the Images

	Number of Images		
	Immature	***Mature***	***Over-mature***
Training	1367	1054	1109
Validation	43	26	35
Testing	25	24	24

In the training, the process can measure the time taken for epoch, loss, and accuracy. Even if we could measure loss and accuracy using only the training dataset it could be misleading due to the over-fitting issues. The best solution for this over-fitting issue is to use a validation data set.

Table II. Summary of the Models Trained

Model	Number of Epoch	Training Accuracy (%)	Training Loss (%)	Validation Accuracy (%)	Validation loss (%)	Average Time per Epoch (s)
EfficientNetV2B1	10	99.38	1.74	100	0.31	102.7
MobileNetV3	10	99.83	0.67	100	0.0066	53.8
ResNetRS50	10	98.70	4.64	100	0.54	291.7
VGG19	30	100	0.0000027	85.58	151.37	6.1

In this project, a completely new set of images was used as the validation data set. During the validation procedure, the model generates a prediction on these new images and categorize them. Subsequently, these predictions are compared to the actual categories to obtain measurements. These measures manifest as val_loss and val_accuracy in the training process, serving as reliable indicators of precision. Also, these readings facilitate comparison with loss and accuracy values to identify the over-fitting during the training process. The testing data set can be used to get a confusion matrix indicating the number of true positives and the number of false positives produced by the model. The summary of the results of the four (04) models is shown in Table II.

Since the accuracy calculated using the validation set tends to be more reliable than other parameters, it can be deemed as the true accuracy of the model. However, to have a more comprehensive understanding, the parameters, including the confusion matrix, training accuracy, and validation accuracy can be considered. According to the results above, the best performance was exhibited by "MobileNetV3". It was able to reach 100% validation accuracy within 10 epochs, and the loss was 0.006%. Not only the validation accuracy but also the training accuracy reached 99.83% at a minimum loss of 0.67%. For "MobileNetV3", the validation accuracy and loss were close to training accuracy and loss, as shown in Tab. 2. Further, the average time taken for an epoch was comparatively less (53.8 s) than other models that reached high accuracy.

IV. Conclusion

In this project, an automated system comprised of a conveyor system was successfully developed to classify the maturity status of papaya fruits. In implementing the project, four (04) pre-trained deep-learning models: EfficientNetV2B1, MobileNetV3, ResNetRS50, and VGG19 were considered. Among the models trained, "MobileNetV3" showed outstanding performance by achieving 100% accuracy within just 10 epochs while maintaining an extremely low loss of only 0.006%. According to the results obtained, transfer learning is a viable approach for the classification of papaya fruits based on their maturity status. The study also highlighted several challenges that need to be addressed to improve the performance of the model including a large and more diverse dataset, more advanced pre-trained models, and the need to consider other factors, namely lighting conditions and image quality, that may affect the performance of the model. Additionally, it would be beneficial to classify papaya fruits into more than three (03) maturity statuses to ensure better product quality and to train the system to classify more varieties of fruits.

Acknowledgment

The financial support provided by the Department of Instrumentation and Automation Technology, University of Colombo is greatly appreciated.

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2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

"Assessing the Effectiveness of Existing Marketing Strategies in Fashion Product Promotion in the 2018-2021 Time Period: Consumer Attitudinal Study in Western Province, Sri Lanka"

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***Abstract*—This study examines the effectiveness of existing marketing strategies in promoting fashion products in the western province region of Sri Lanka from the consumer perspective. The study covers 2018-2021 and involves a quantitative research design, which collects data from 250 consumers who purchased fashion products from various retailers in the region. The study results show that social media marketing and word of mouth are the most effective marketing strategies for promoting fashion products in the Western province. The study provides insights for fashion marketers to develop marketing strategies and effectively increase sales and market share in this region. The study recommends that fashion marketers focus on developing effective social media marketing strategies and especially encouraging customers to share their positive experiences through word of mouth, especially when the consumer becomes an effective influencer with a relevant level to cater to that would be more effective.**

Keywords—Fashion marketing, promotion, consumer attitudinal, western province, Sri Lanka

I. INTRODUCTION

Fashion is one of the fastest-growing industries in Sri Lanka, especially in the Western Province, where many fashion brands and retailers exist. However, promoting fashion brands in this sector has become challenging due to increasing competition and changing consumer preferences. It is also important to communicate through effective marketing strategies. This study aims to examine the effectiveness of existing marketing strategies in promoting fashion products in the Western Province of Sri Lanka from the consumers' perspective. The study covers 2018-2021 and collects quantitative data from 250 consumers who purchased fashion products from various regional retailers. To achieve the goal, the following research questions guided this study.

1. What are the existing strategies for fashion promotion in the Western Province of Sri Lanka?
2. How effective are these marketing strategies in promoting fashion brands in the minds of consumers?
3. What factors influence consumer preferences for different marketing strategies?

The research is based on a theoretical framework of consumer behavior and marketing strategies. The study contributes to the existing literature on fashion marketing by providing valuable insights for fashion marketers to develop effective marketing strategies to promote their products in the western province region of Sri Lanka on the floor.

II. METHODOLOGY

This study adopts a quantitative research design and collects data from 250 consumers who purchased fashion products from various retailers in the Western Province of Sri Lanka. The study uses a survey questionnaire as the main method of data collection. The survey questionnaire consists of two parts. The first stage collects information on consumer demographics, while the second stage collects information on consumers' perceptions of existing marketing channels to promote fashion products, their effectiveness, and what is preferred in terms of marketing strategies. The data collected were analyzed using descriptive and indicative statistics, such as regression analysis and ANOVA. Data were analyzed using SPSS version 25.

III. RESULTS

The results of the study show that social media marketing and word of mouth are the most effective marketing strategies to promote fashion products in the western province region of Sri Lanka. The study found that consumer perception of social media marketing and word of mouth and their behaviors in the camp. The study also found that consumers' age, gender, and income influence their preferences for different channels. For example, most younger consumers prefer social media marketing, while most older consumers prefer traditional marketing channels such as television and printed media. Word of mouth with proper recommendations from previous customer experiences and consumer feedback would increase the confidence to purchase products from the same retailer as a loyal or new customer. Even on social. media, customers would check on previous feedback on e-media pages to get an idea before purchasing.

TABLE 1. DEMOGRAPHIC CHARACTERISTICS OF PARTICIPANTS

Demographic Variable	**Frequency**
Gender	
Male	120
Female	130
Age (years)	
18-25	70
26-35	100
36-45	50
46 and above	30

Monthly Income (LKR)	
< 50,000	100
50,000-100,000	120
> 100,000	30

Note: LKR stands for Sri Lankan Rupees.

IV. Discussion

The study results are consistent with existing literature on fashion marketing and consumer behavior. The study gives fashion marketers insights into developing effective marketing strategies to increase sales and market share in the Western Province Region of Sri Lanka. The study also highlights the importance of understanding marketing channel consumer preferences based on age, gender, and income.

A. Effectiveness of Social Media Marketing and Word of Mouth Strategy

Social media marketing and word of mouth have emerged as the most powerful marketing strategies for the promotion of fashion products in the Western province of Sri Lanka. These findings are consistent with a wide body of literature on the topic. In particular, social media platforms have become impactful tools for brand promotion and customer engagement (Smith & Zook, 2019) [1]. Nourished by recommendations from prior customers and customer feedback, word of mouth plays an important role in customer trust and loyalty (Godes & Mayzlin, 2004) [2]. The effectiveness of social media marketing can be attributed to its capability to reach a wider and more diverse audience, especially among young consumers, who show an intelligible preference for this medium. The visual nature of fashion products aligns seamlessly with the visual-centric nature of social media platforms (Tuten & Solomon, 2017).) [3]. In addition, younger users often seek validation and inspiration from their peers on social media platforms, making these channels more influential (Smith & Zook, 2019) [1].

But word of mouth harnesses the power of personal recommendations and exploits the trust of interpersonal relationships. This is in line with previous research that emphasizes the impact of word of mouth on consumer decision-making (Godes & Mayzlin, 2004) [2]. The survey findings emphasize the importance of providing a positive customer experience and encouraging satisfied customers to share their experiences and recommendations (East, Hammond, & Lomax, 2008) [4].

B. Effects of Demographic Factors

Research also shows that consumer demographics, including age, gender, and income, have a significant impact on their preferred shopping style. The literature supports this finding. Due to the convenience of technology and digital communication, younger users are gravitating towards digital channels such as social media (Smith & Zook, 2019) [1]. In contrast, older consumers mostly prefer traditional marketing channels such as television and print media, which have had an impact throughout their lives (Sheth & Mittal, 2004) [5]. Demographically understanding these changes is important in order to develop marketing strategies for specific target audiences.

C. Implications for Fashion Marketers

The implications of this study for fashion retailers in the Western Province of Sri Lanka are profound. In order for marketing strategies to be effective, businesses need to invest in active social media presence and promote product recommendations provided by customers. These strategies should be emphasized especially when targeting younger consumers. Additionally, fashion retailers need to consider multiple strategies to ensure they meet the preferences of diverse consumers. By segmenting marketing strategies according to age, gender, and income, companies can create highly targeted, engaging campaigns, thus increasing their chances of gaining market share has the large share increased.

V. Conclusion

The study concludes that social media marketing and word of mouth are the most effective marketing strategies to promote fashion products in the western province region of Sri Lanka. The study recommends that fashion marketers focus on developing effective social media marketing strategies and especially encouraging customers to share their positive experiences through word of mouth, especially when the consumer becomes an effective influencer with a relevant level to cater to that would be more effective. Fashion marketers need to consider the age, gender, and income levels of their target customers when choosing marketing channels to reach and communicate with them.

Acknowledgement

I thank all the customers and consumers who participated in this research and provided valuable insights. I also acknowledge the teachers and Lecturers who provided relevant knowledge on fashion and marketing areas in different curriculums.

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2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

Tomato (*Solanum lycopersicum*) Growth, Yield, and Taste Components Under Water Stress in Sri Lanka's Dry Zone

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***Abstract*—This study aimed to investigate the effects of water stress on the growth, yield, and taste components of the "Padma" tomato variety, offering valuable insights for farmers contending with limited water resources in the dry zone of Sri Lanka. Employing three treatments—drought stress, control, and excess water stress—the research reveals that drought stress significantly diminishes plant wet weight (169.9±29.7 g) and dry weight (66.7±11 g), impacting parameters like branches, plant height, and leaf count. In the realm of yield and fruit dimensions, excess water stress proves advantageous, yielding larger fruit diameters (3.7±0.25 cm) and higher yield per plant (742±196), while drought stress results in lower values. These findings not only enhance our understanding of water stress effects on tomato cultivation but also offer practical guidance for farmers in water-scarce regions, aiding them in optimizing crop management strategies for sustainable and efficient production**

***Keywords*—Tomato, water stress, plant growth, fruit quality, Brix, pH**

I. Introduction

Tomato fruit is a highly perishable commodity with a limited shelf life under normal temperature conditions. The flavor of tomatoes is influenced by several factors, including their sugar, acid, and volatile chemical content, which can vary depending on the variety and environmental conditions. While genetics governs the flavor profile of tomatoes, environmental elements such as sunlight, soil nutrients, and water availability can also impact these characteristics. Water is a crucial factor in tomato cultivation, as it significantly determines yield and fruit quality. Optimal water supply throughout the growing period is essential for achieving higher yields and optimal fruit quality in tomatoes [1]. However, dry zone areas in Sri Lanka often face water scarcity issues, with drought being a particularly challenging climate event in these regions. Drought stress has been found to limit the growth and yield of tomato plants, leading to reduced plant height, leaf size, stem diameter, and poor fruit and seed quality. Therefore, this study aims to address the yield and taste components of tomatoes cultivated in the dry zone areas of Sri Lanka under water stress conditions.

II. Methodology

The experiment was conducted in a Poly house located on Raja Road, Tirunelveli, East Jaffna, Sri Lanka, from December 2022 to May 2023. The tomato cultivar ‘Padma’ was selected for this experiment and after three weeks seedlings were planted in black-colored poly bags filled with a 2:1 topsoil to cow manure ratio. In this experiment, three water stress conditions were used as treatments: T_1 - drought stress treatment (100 ml water/day), T_2 - control treatment (200 ml/day - determined by analyzing soil field capacity of this area), and T_3 - excess water stress treatment (400 ml/day). Each treatment had 18 replicates. Plant height and number of leaves were measured at weekly intervals and at the end of the growth period number of branches, wet weight, and dry weight of the plants were measured. Yield parameters were measured as wet weight, number of fruits, and fruit diameter. Harvesting was done when fruits reached their full maturity, and harvested samples were prepared for Brix% and pH analysis. Statistical analysis was performed using the ANOVA function of the MINITAB Statistical Package version 19.

III. RESULTS

A. Growth Parameters

a. Wet Weight and Dry Weight

Drought stress treatment had the significantly lowest mean value in plant wet weight (169.9±29.7 g) and had the lowest mean value in plant dry weight (66.7±11 g) (Tab. 1).

b. Number of Branches

The number of branches did not differ significantly between treatments. Drought stress treatment showed a lower mean value (3.61±0.56) than excess water stress treatment (Tab. 1).

c. Plant height

Plant height did not show a significant difference in means between treatments except in the 8th week where drought stress treatment had a lower mean value (113.7±7.9 cm) than excess water stress treatment (Tab. 2).

d. Number of Leaves

Significant differences between the treatments were observed during the 8th week where drought stress treatment displayed significantly lowest mean value (11.7±1.2) (Tab. 3).

B. Yield, Fruit Parameters and Taste Components

a. Fruit Diameter

Excess water stress treatment had the highest mean value (3.7±0.25 cm) than drought stress treatment and control treatment (Tab. 4).

b. Fruit Weight

Drought stress treatment showed a mean value of 33.6±4.3 g which was lower than excess water stress treatment (Tab. 4).

c. Number of Fruits

The number of fruits did not significantly vary between treatments. Drought stress treatment had the lowest mean value which is 20.1±2.7 (Tab. 4).

d. Yield per Plant

Excess water stress treatment showed the highest yield/plant. Compared to the excess water stress treatment drought stress treatment had a lower mean value which is 742±196 (Tab. 4).

e. Brix % and pH

Significantly similar mean brix % and pH values were noted between drought stress treatment and control treatment (Tab. 4).

TABLE I: RESULTS OF GROWTH PARAMETERS

Treatments	Plant Growth Parameters		
	Number of Branches	***Plant Dry weight(g)***	***Plant Wet Weight(g)***
T1	3.61 ± 0.56 a	66.7 ± 11 a	169.9 ± 29.7 b
T2	3.1 ± 0.46 a	96.2 ± 12.5 a	301.9 ± 38.8 a
T3	3.9 ± 0.52 a	90.3 ± 10.3 a	299.2 ± 35.2 a

Values in each column represent the means of 18 replicates ± SE (Standard Error). The mean followed by the same letter within each column is not significantly different at $p<0.05$

TABLE II: RESULTS OF PLANT HEIGHT

Treatments	Plant Height(cm)				
	1st week	***4th week***	***6th week***	***8th week***	***11th week***
T1	92.3 ± 2.3 a	104.6 ± 3.7 a	111.1 ± 3.9 a	113.7 ± 7.9 a	86.6 ± 13.4 a
T2	95.3 ± 1.8 a	108.4 ± 2.5 a	116.5 ± 3.4 a	109.4 ± 10.2a	67.0 ± 14.7 a
T3	90.6 ± 6.5 a	104.4 ± 8.3 a	110.1 ± 8.8 a	121.1 ± 9.5a	81.9 ± 15.2a

Values in each column represent the means of 18 replicates ± SE (Standard Error). The mean followed by the same letter within each column is not significantly different at $p<0.05$.

TABLE III: RESULTS OF THE NUMBER OF LEAVES

Treatments	Number of Leaves				
	1st week	***4th week***	***6th week***	***8th week***	***11th week***
T1	15.3 ± 0.5 a	15.6 ± 0.9 a	14.7 ± 1.2 a	11.7 ± 1.2 b	9.5 ± 1.8 a
T2	15.2 ± 0.4 a	18.5 ± 0.6 a	15.0 ± 0.8 a	13.5 ± 1.5 ab	6.9 ± 1.6 a
T3	15.3 ± 1 a	17.5 ± 1.6 a	15.3 ± 2 a	18.1 ± 2.5 a	10.7 ± 2.5 a

Values in each column represent the means of 18 replicates ± SE (Standard Error). The mean followed by the same letter within each column is not significantly different at $p<0.05$.

TABLE IV: RESULTS OF YIELD AND FRUIT PARAMETERS

Treatments	Fruit and Yield Parameters			
	Fruit Weight (g)	***Yield/ plant***	***Number of Fruits***	***Fruit Diameter (cm)***
T1	33.6 ± 4.3 a	742 ± 196. a	17.2 ± 3.1 a	3.4 ± 0.15 a
T2	33.6 ± 3.9 a	673.5 ± 93.8 a	19.8 ± 1.1 a	3.4 ± 0.12 a
T3	42.9 ± 4.9 a	1011 ± 193.5 a	20.1 ± 2.7 a	3.7 ± 0.25 a

Values in each column represent the means of 18 replicates ± SE (Standard Error). The mean followed by the same letter within each column is not significantly different at $p<0.05$.

TABLE V: RESULTS OF TASTE COMPONENTS

Treatments	Taste Components	
	Brix%	***pH***
T1	5.9 ± 0.48 a	3.4 ± 0.06 a
T2	6.1 ± 0.39 a	3.4 ± 0.07 a
T3	5.0 ± 0.39 a	3.2 ± 0.2 a

Values in each column represent the means of 18 replicates ± SE (Standard Error). The mean followed by the same letter within each column is not significantly different at $p<0.05$

IV. DISCUSSION

Tomato is sensitive to a variety of environmental challenges, particularly excessive temperature, drought, salinity, and insufficient moisture, and has an adverse impact on plant growth, development, and production. Drought conditions are caused by a scarcity of water due to a decrease in rainfall and an increase in the frequency of dry periods. This study examined the effects of various water treatments on various characteristics of fruit and plant growth parameters. In this study, drought stress treatment showed a lower mean value than the excess water stress treatment during the 8th week in terms of plant height. This aligns with prior research reporting drought stress can reduce plant height [1]. Drought stress treatment had significantly the lowest number of leaves during the 8th week suggesting that drought stress reduces leaf growth [2]. Drought stress treatment showed a significantly lower mean value in terms of plant wet weight which implies that drought stress can reduce plant weight. Prior studies investigated how different crops respond to drought stress. For instance, drought stress has significant effects on the chili pepper cultivars' taste components, fruit size, and overall productivity [3] and the stress condition was affected in the taste component synthesis cycles ex. Capsaicinoids synthesis cycle [4]. When considering the other environmental stress conditions present findings were tallied with the findings for the salinity stress conditions [5] of chili pepper cultivars which were in the same family as tomatoes. Along with this, a prior report showed the drought stress treatment had the lowest number of fruits [6] and drought stress treatment showed a lower mean value in terms of Yield/plant when compared to the excess water stress treatment, suggesting drought stress can reduce total yield/plant in tomato plants. Drought stress treatment showed significantly similar pH and Brix% values when compared to the control treatment. This implies that drought stress might not substantially impact sugar content and fruit acidity. This is consistent with studies noting minimal changes in fruit quality attributes under drought stress conditions [7].

V. CONCLUSION

The findings of our study provide valuable insights into the effects of drought stress on tomato cultivation in the dry zone of Sri Lanka. The results suggest that drought stress affects plant growth parameters, fruit characteristics, and yield/plant in tomatoes. These findings can guide future research and assist farmers in making informed decisions to improve tomato production in water-stressed environments. However, further research is needed to fully understand the underlying physiological mechanisms and optimize water stress conditions for tomato cultivation in water-limited environments.

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2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

Suitability of Different Supplements for the Growth and Yield of Oyster Mushroom Cultivation

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***Abstract*—There are several species of edible mushrooms grown around the world and among them, particularly *Pleurotus ostreatus*, are highly nutritious and in high demand worldwide. In Sri Lanka, *P. ostreatus* is widely cultivated commercially and the nutrient requirement is supplied with different supplementations. This experiment was conducted to study the effects of different nutrient supplements on the growth and yield of *P. ostreatus*. The study tested different treatments, including a supplement mixture, corn flour, green gram flour, rice flour, and chickpea flour. The results showed that the mushrooms supplemented with chickpea flour showed a higher mycelial growth rate compared to other treatments. However, corn flour showed better results in terms of fruiting bodies per bag in both flushes. In the first flush, the yield (g/bag) was higher with green gram flour (137.80±17.48 g), followed by corn flour (126.95±20.16g). In the second flush, the mixture of supplements (144.95±14.99g) and corn flour (119.80±9.57 g) showed higher yields. Lastly, corn flour (246.75±22.64 g), the mixture of supplements (245.70±23.36 g), and green gram flour (244.05±24.01 g) resulted in a higher total yield. Since attention should be given to improving the total yield of a mushroom cultivation use of, corn flour, the mixture of supplements and green gram flour as the supplements can be recognized as more beneficial compared to the others.**

Keywords—Pleurotus ostreatus, nutrient supplementation, mycelial growth rate, yield

I. INTRODUCTION

Edible mushrooms can serve as a source of nutritious food or medicinal supplements, with some types providing both benefits. It is widely recognized that mushrooms possess these properties [1], which may have resulted in increased production and consumption worldwide [2]. Among the number of edible mushrooms, the *Pleurotus* genus attains considerable attention among growers and consumers. The genus *Pleurotus* has approximately 40 species, which are often known as "oyster mushrooms" [3], [4]. Most of the time, they can be seen under tropical and subtropical climates such as Asia, Europe, and Africa [2], [5] while they can be easily artificially farmed [3]. The majority of these species are produced in China, accounting for 87% of the world's total production [2]. *Pleurotus ostreatus* belongs to the family Pleurotaceae and it has a broad, fan, or oyster-shared cap with a length between 5 to 25 cm, while the color can range from white to grey or tan to dark brown. The margin is rolled inwards when young and smooth but is often lobed and wavy [3].

Many studies have been conducted to discover mushrooms' chemical composition, nutritional value, and health benefits. *P. ostreatus* is a good source of proteins and amino acids. They can provide all nine essential amino acids for humans, and they are especially high in lysine and leucine, which are deficient in most cereal diets [6]. It is a good source of carbohydrates, vitamins such as thiamine, riboflavin, niacin, and folates and a good source of minerals such as K, P, Zn, Cu, Mg, B, Mn, Ca, Na, and Fe [7, 8, 9]. Additionally, this diet can be considered well-balanced due to its low fat and energy levels and its higher

amounts of dietary fiber and other beneficial compounds [10]. Meanwhile, several studies have recorded their health benefits such as antioxidant effects [4, 11] antibacterial effects [12], antiviral effects [13], anti-diabetic effects [14], anti-hyperlipidaemic effects [15, 16] and many more.

The ideal temperature for the growth of oyster mushrooms is 20° to 30° C, with humidity ranging from 55-70% during 6 to 8 months of the year [17]. For the growth of mushrooms usually as a nutritional source C (Carbon), N (Nitrogen), and other inorganic compounds are required. However, oyster mushrooms require a higher amount of C and a lesser amount of N. Since cellulose, hemicellulose, and lignin can act as major sources that can provide C, materials such as straw (rice, wheat), leaves (banana), cotton seed hulls, corncobs, sugarcane bagasse, sawdust, and waste paper can be used as the substrate for the growth of mushrooms [18], [19]. The oyster mushroom can use a wider range of waste materials as a substrate than any other fungus, and as a result, transform them into valuable vegetable food that is comparable in nutritional value to non-vegetarian food [20]. These naturally occurring cellulose, hemicellulose, and lignins only contain a certain amount of their nutrient elements, thus they need to be supplemented with chemical and biological supplements. The introduction of nutritional additions to the substrates used for mushroom production constitutes the agronomic procedure known as mushroom supplementation. Adding external nutrients can enhance the productivity of mushroom cultivation. However, there is debate surrounding the nutritional needs of mushrooms and the usefulness of new commercial additives [20, 21].

Though there are several commercially available supplements for the producers in the market, huge attention has been gained by the low-cost supplements which are considered waste materials for some other processes [21]. Such as peanut waste [22], cotton seed cake, soybean meal, urea, ammonium sulfate [23], olive mill waste [24], rice husk [25], and grapeseed meal [26]. In Sri Lanka, sawdust is a material that is widely utilized and favored by the commercial sector. To cultivate oyster mushrooms, it is supplemented with rice bran and a protein supplement. In the manufacture of substrates, protein supplements like soy and green gram powder are usually used. However, the cost of production can be reduced by substituting less expensive N sources, such as animal dung, which can provide a significant amount of secondary and main plant nutrients [27]. Currently, the Department of Agriculture's recommendation is to use sawdust (20 kg), rice bran (2 kg), CaO (400 g), soya flour (200 g), and $MgSO_4$ (40 g) for 50 packets of mushrooms [28]. In Sri Lanka, farmers commonly use a commercially available mixture of nutrient supplements which includes corn, chickpea, rice, green gram, and soya flour. When cultivating mushrooms with varying levels of supplementation, there were significant differences in growth, yield, and quality parameters [29]. Therefore, this experiment was conducted to study the suitability of using chickpea flour, green gram flour, corn flour, and rice flour for the growth and yield of oyster mushrooms as nutrient supplementations.

II. METHODOLOGY

The experiment was conducted at the "Green Core Techno Park", SAERC, SLTC Research University (6.8557° N, 80.0926° E, and 27 m above mean sea level), Ingiriya Road, Padukka, Sri Lanka from January 2023 to May 2023.

For this experiment as the substrate, sawdust (100 kg) supplemented with dolomite (2 kg), rice bran (10 kg), $MgSO_4$ (0.2 kg), gypsum (1 kg), and nutrient supplement (1.5 kg) were used to prepare 250 mushroom bags. To assess the impact of nutrient supplements, five different supplements were used as treatments within a Complete Randomized Design (CRD). These treatments included a supplement mixture (mixture of chickpea flour, green gram flour, corn flour, rice flour, and soya flour mixed in similar amounts) which most of the mushroom cultivators use as the nutrient supplement (T1), corn flour (T2), green gram flour (T3), rice flour (T4), and chickpea flour (T5), which were mixed separately. To add $MgSO_4$, it was dissolved in water and applied to the mixture, after which a moist mixture was created. Approximately 500-600 g of the moist mixture was then filled into a transparent polythene bag that measured 33 × 18 cm. The bags were sterilized for 2-3 hours by steaming them in a metal barrel while providing constant heat throughout the period. After the bags had cooled down completely, they were inoculated under a sterilized environment with *Pleurotus ostreatus* spawns purchased from the commercial market. The bags were then transferred to a dark room at a temperature of 28 °C while maintaining a relative humidity of 90 – 95 %. For three weeks, the vertical length (cm) of the mycelium was measured from four faces, once a week [18]. Once the mycelium had grown completely, one end of the packet was cut open to facilitate the mushroom growth out of the bag. The relative humidity was maintained at 85-90% and water was applied twice a day, while the temperature was kept around 25 – 28 °C within the growing chamber. The number of fruiting bodies and their fresh weight (g) were measured daily. These measurements were taken in two separate flushes, and the total measurements were calculated.

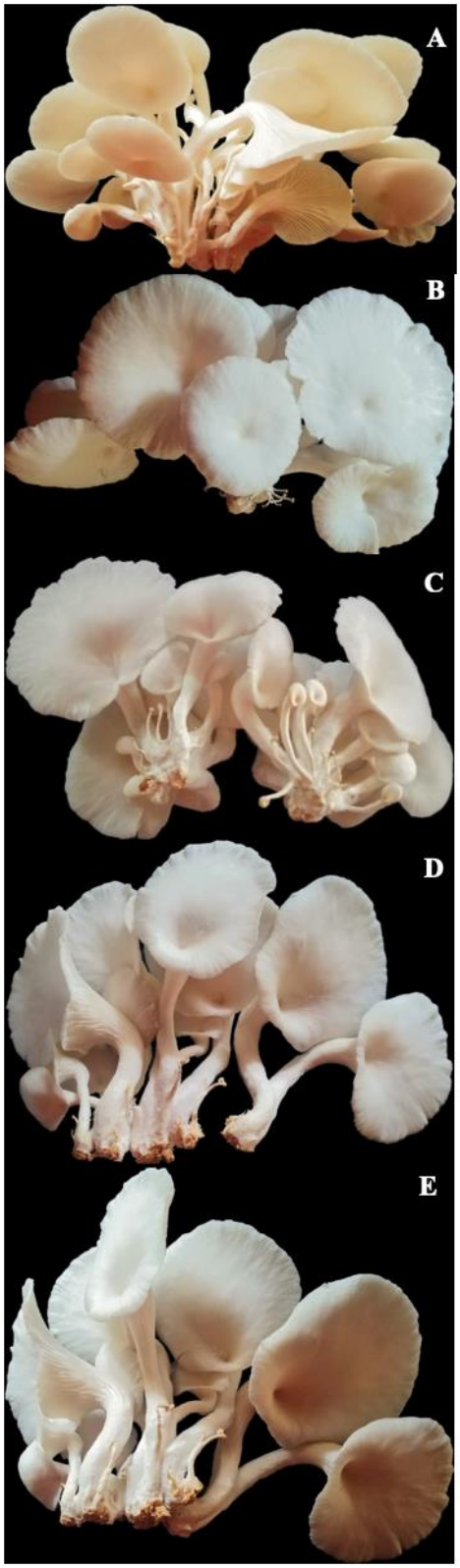

Fig.1. Harvested mushrooms from growing bags supplemented with Supplement mixture (A), Corn Flour (B), Green Gram Flour (C), Rice Flour (D) and Chickpea Flour (E)

Data were analyzed using the ANOVA test and the mean separation was done by using Fisher's least significant difference (LSD). As the statistical analysis software Minitab Version 19 was used.

III. Results and Discussion

A. *Mycelial Growth Rate*

According to the current study, there were significant differences among treatments for the mycelial growth rate during the three consecutive weeks studied ($p<0.05$). A comparatively higher mycelial growth rate compared to the other treatments, could be observed with the mushrooms supplemented with chickpea flour (T5) in all three weeks (Fig.2.). Several other studies have shown that chickpea flour can be used as a supplement for the growth of mushrooms in different substrates such as corn cobs, grasses, and cotton waste [23], [30], [31]. Meantime, reference [32] found that with the increment in the application rate of chickpea flour, the time taken to the completion of spawn running had reduced [32]. They found that when 2.5% chickpea powder was amended, spawn running was shown to be completed earlier. However, some opposite results have been found by [33] revealing that with the increased supplementation percentage of corn flour and wheat bran, the rate of mycelial growth has reduced gradually and such rapid mycelial development suggested that these levels of supplementation contained a greater C to N ratio (C/N), which favored rapid mycelial growth. Also, this was most likely owing to the high N level, which has been shown to hinder mushroom growth when present in excess in the substrate [33].

B. *Number of Fruiting Bodies*

There were significant differences among the supplements in both flushes separately and together for the number of fruiting bodies ($p<0.05$). Comparatively, a higher number of fruiting bodies were given with the corn flour supplement (T2). However, in the first flush other than corn flour, green gram flour (T3) also resulted in a higher number of fruiting bodies. Since the main focus should be given to the total number of fruiting bodies it can be said that corn flour supplement has a better effect in increasing the number of fruiting bodies compared to other supplements (Table I). The lignocellulosic substrate of wood components' poor availability of N is frequently seen as a barrier to its usage as a mushroom substrate therefore, supplemental N is crucial for the growth of fruiting bodies in mushrooms grown in sawdust [34].

On the other hand, chickpea flour had some concerns in terms of the number of fruiting bodies because it had a lower number compared to other treatments though its mycelial growth rate was higher. This shows the inability of mycelia to utilize the substrate fully therefore a yield reduction had resulted. This

demonstrates that mycelial growth and mushroom output have different necessities [35]. On the other hand, [31] showed that *P. ostreatus* grown in cotton waste substrate supplemented with chickpea flour had better results, however, the results were lower compared to rice bran and wheat bran supplementations [31].

Except for the chickpea flour supplementation (T5) with all the other treatments a slight reduction in the number of fruiting bodies could be observed with the second flush compared to the first flush (Table I). Similar findings were shown by [35], and they have shown that the fact that fewer fruit bodies were recorded for each flush on average shows that the type and amount of N present in a substrate after each flush impact how much cellulose degrades, which in turn affects the yield [35].

C. Mushroom Yield

Mushroom yield in both flushes and the final total yield was significantly different in the tested supplements ($p<0.05$) (Table II). In the first flush, a higher yield could be observed with mushroom bags supplemented with green gram flour (T3), followed by corn flour (T2). The mixture of supplements (T1) was given a higher yield during the second flush, followed by corn flour (T2). Most importantly, corn flour (T2), the mixture of supplements (T1), and green gram flour (T3) gave a higher total yield. Similar findings have been shown, where 30% corn powder supplemented with rice straw as a substrate to cultivate milky white mushrooms showed better growth and yield compared to other supplements [36] and 20 and 8 % corn flour supplemented with the substrate of maize stalk residues to cultivate *P. ostreatus* [33].

When protein-rich additives are added to mushroom substrates, it can increase both the quality and quantity of the yield, according to reference [21]. In this study, all the supplements used are good sources of proteins Mixture of supplements, corn, green gram, rice, and chickpea flours have protein contents of 20.3%, 9.42%, 23.86%, 6.61%, and 19.30% respectively [37]. Although corn flour has a relatively lower amount of protein content, it showed better results in terms of yield in the current experiment. The composition and amount of supplement added to the growing bag can significantly affect the final yield [34]. Reference [33] concluded that the growth of *Pleurotus* species is favored by a substrate low in N content, which may explain why they obtained the best yield using 8% and 20% corn flour [33].

It is recommended to conduct further investigations on the mixing rates of current supplements to determine if a reduction in mixing rate would impact yield quality and quantity. Also conducting a cost-benefit analysis can help identify the feasibility of using these substrates among farmers.

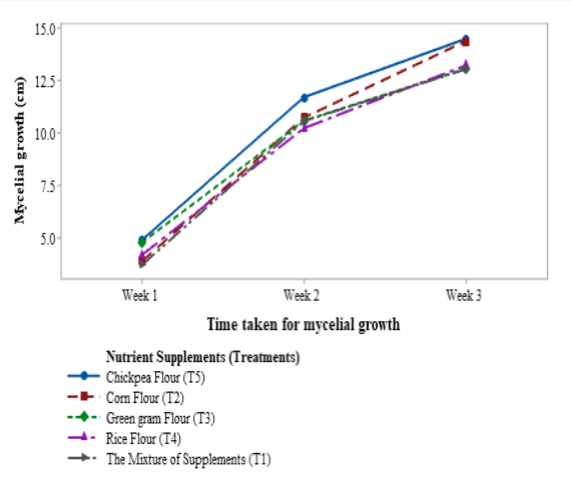

Fig.2. Mycelial growth in mushrooms with different nutrient supplements

TABLE I. NUMBER OF FRUITING BODIES (NFB) PER BAG IN FIRST FLUSH, SECOND FLUSH, AND TOTAL NFB

Nutrient Supplement	First Flush	Second Flush	Total NFB
The Mixture of Supplements (T1)	20.75 ± 3.24^{ab}	20.25 ± 2.82^{ab}	41.00 ± 4.15^{abc}
Corn Flour (T2)	25.50 ± 4.42^{a}	21.55 ± 2.31^{a}	47.05 ± 5.37^{a}
Green gram Flour (T3)	25.40 ± 3.16^{a}	17.45 ± 2.23^{ab}	42.85 ± 3.39^{ab}
Rice Flour (T4)	19.25 ± 3.52^{ab}	13.85 ± 2.03^{b}	33.10 ± 3.67^{bc}
Chickpea Flour (T5)	14.30 ± 1.70^{b}	16.10 ± 2.32^{ab}	30.40 ± 3.11^{c}

Values in each column represent the means of 20 replicates ± SE (Standard Error). The mean followed by the same letter within each column is not significantly different at $p<0.05$.

TABLE II. MUSHROOM YIELD PER BAG IN THE FIRST AND SECOND FLUSHES AND THE TOTAL YIELD

Nutrient Supplement	First flush (g)	Second flush (g)	Total yield (g)
The Mixture of Supplements (T1)	100.75 ± 14.56^{abc}	144.95 ± 14.99^{a}	245.70 ± 23.36^{a}
Corn Flour (T2)	126.95 ± 20.16^{ab}	119.80 ± 9.57^{ab}	246.75 ± 22.64^{a}
Green gram Flour (T3)	137.80 ± 17.48^{a}	106.25 ± 13.85^{b}	244.05 ± 24.01^{ab}
Rice Flour (T4)	93.80 ± 12.06^{bc}	92.45 ± 15.69^{b}	186.25 ± 17.58^{bc}
Chickpea Flour (T5)	80.60 ± 8.21^{c}	93.25 ± 12.37^{b}	173.85 ± 15.31^{c}

Values in each column represent the means of 20 replicates ± SE (Standard Error). The mean followed by the same letter within each column is not significantly different at $p<0.05$.

IV. CONCLUSION

In commercial mushroom cultivation, nutrient supplementation significantly impacts yield and quality. The current experiment explored alternative supplements to the common mixture used by farmers. Among corn flour, green gram flour, rice flour, and chickpea flour tested with chickpea flour showed the fastest mycelial growth but gave concerns about yield. Corn flour and green gram flour, along with the supplement mixture, performed well in terms of yield, indicating their potential as effective alternatives. Further research is needed to determine optimal mixing ratios for these supplements, to reduce ratios without compromising final yield. This study contributes valuable insights for improving mushroom cultivation practices in Sri Lanka.

ACKNOWLEDGMENT

This research was financially supported by the Sustainable Agriculture and Environment Research Centre (SAERC) of Sri Lanka Technological Campus, Meepe, Padukka, Sri Lanka.

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2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

Health Safety and Quality of Guava Produced in Selected Guava Production Systems in Anuradhapura and Matale Districts

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***Abstract*—Guava (*Psidium guajava* Linn.) is one of the principal tropical fruits that is largely consumed and has a high export potential in Sri Lanka. Along this line, addressing the question of "health safety of guava fruits" under different crop management conditions was found to be a timely and important topic, because the consumer concerns over the fresh fruit quality and health safety have increased substantially in recent years. Therefore, this study was conducted to determine whether there is a correlation between crop management conditions and the fruit qualities and pesticide residue level of guava. For the qualitative assessments, guava samples were collected from farmer fields at the harvesting maturity stage. Total Soluble Solid (TSS), titratable Acidity (TA), fruit volume, fruit weight, fruit diameter, fruit firmness, peel color values, and pesticide residue level were quantified in fresh samples. Based on the results, the residues of common pesticides were not detected in all the samples. Meanwhile, the crop management intensity was found to be not significant ($P<0.05$) on all the selected quality parameters of fresh guava. The low rate of application due to the high cost of pesticides and adherence to safety guidelines were found to be the most probable reasons for this situation. As a summary of the results, it can be concluded that present-day crop management in guava cultivations does not have any harmful effect on fresh fruits with respect to pesticide residues. However, this conclusion needs verification through repeated studies, using a better sampling strategy, before recommending the health safety of fresh guava in Sri Lanka.**

***Keywords*—Pesticide residue, guava, gas chromatography-mass spectrometry, crop management**

I. Introduction

Guava (*Psidium guajava* Linn.), one of the principal tropical fruits, is extensively consumed in Sri Lanka in its fresh form and holds significant export potential. It belongs to the family Myrtaceae. Guava is called "the apples of the tropics". It is because fresh guava fruit is a good source of plenty of vitamins, minerals, fibers, and antioxidants. Within Sri Lanka, guava has high demand throughout the year. This fruit crop can grow under wider climatic and soil conditions. There can be identified several guava-based cropping systems like mono-cropping systems, home gardening, Intercropping systems, multiple cropping systems, etc. The intensity of crop management differs from one cropping system to another. There have been about 177 pathogens reported in the guava plant [1]. These pathogens cause several pre- and post-harvest diseases of guava. Therefore, pesticide application in the guava production systems is high. Studies on the impact of pesticides on human health showed that toxicological exposure caused by the intake of foods is five times higher compared to other exposures like air and water [2].

Therefore, conducting a well-planned sampling-based pesticide residue analysis will bring about much-needed evidence to assure health safety under different crop management intensities, enabling the enforcement of regulations on pesticide usage. Moreover, the trust built within consumers on health safety will further increase the demand for guava in the local market, positively influence per capita fruit intake among Sri Lankans, and contribute to the much-needed import substitution in the fruit sub-sector in the agri-food system of Sri Lanka. Therefore, our objectives were to determine the level of fruit quality and pesticide residues in guava grown under different crop management conditions in the Anuradhapura and Matale districts and to determine the use of "freedom from pesticide residues" as a quality parameter for guava.

II. Methodology

A. Field Survey

The initial step involved conducting a comprehensive questionnaire-based field survey in 46 mini orchards/guava farms, which were identified in the Anuradhapura district (including Tirappane, Kekirawa, Galnewa, Ipalogama, Kekirawa, Thalawa, Thambuththegama, Rajanganaya) and Matale district (specifically, Dambulla and Wewala). These orchards were selected based on recorded guava cultivation data from the National Institute of Post-Harvest Management, Anuradhapura. Multiple visits were undertaken to interview farmers, and the questionnaire was completed simultaneously.

B. Grouping of Farmers

Based on collected primary data from the survey, the cropping system's nature, and management condition level

were identified. Management intensity indexes (Crop Management Index, Pest Management Index) were calculated to group guava farms based by their management practices as described by [3] and [4]. The calculation of these indexes involved interviewing farmers to evaluate the utilization of seven external input variables: synthetic fertilizers, organic fertilizers, insecticides, weedicides, fungicides, nematicides, and irrigation. The pest management index was also considered when calculating the crop management indexes. Based on the obtained crop management intensity index scores falling within the ranges of 7-11, 12-16, and 17-21, the guava farms were then classified into three distinct categories reflecting low, intermediate, and high levels of crop management intensity, respectively.

C. Sampling of Guava Fruits

For the sampling of guava for the laboratory analysis, five farms were selected randomly within each category of crop management intensity (treatments). The sample size was 5 fruits, gathered from 5 trees (replicates) from each farm (replicate). Guava fruits were manually harvested at harvesting maturity and an effort was made to pick fruits located in the middle part of the canopy to avoid over or under estimation of pesticide residues. All collected samples were properly wrapped, labeled and transported to the National Institute of Postharvest Management (NIPHM) in Anuradhapura.

D. Analysis of Fruit Quality Parameters

At the laboratory, various fruit quality parameters were assessed. These included Total Soluble Solids (TSS) measured using a digital refractometer, firmness using a penetrometer, and for the titratable acidity, the aliquot was titrated against 0.1M NaOH, and the external qualities such as fruit diameter measured precisely using a digital caliper with an accuracy of ± 0.01 mm, fruit weights using a top-loading electronic balance with an accuracy of ±0.01 g, fruit Volume employing the water displacement method, and fruit color using chroma meter.

E. Pesticide Residue Analysis

After the quality analysis, 50g of sample was prepared and the pesticide residues were extracted by the QuEChERS method (Quick Easy Cheap Effective Rugged and Safe) according to the AOAC official method [5] and the pesticide residual levels were determined by gas chromatography (GC-2016, TYPE: Z326K, Germany).

F. Statistical Analysis

Experiment was conducted as a Completely Randomized Design (CRD) and Analysis of Variance (ANOVA) was performed. Means were compared using LSD test with Minitab software, version 20.0.

III. Results and Discussion

A. Field Observations

In Anuradhapura district, guava production spans small, medium, and large scales, with some farmers exporting while others serve the local market. Historically, fruit flies and root-knot nematodes were significant pests, but root-knot nematodes are now less problematic. This led some farmers to switch to alternative crops. Most guava farmers prefer manual weeding with grass cutters due to costly and limited chemical weedicides, resulting in varied pesticide application frequencies.

B. Pesticide Residual Levels Detection

Analysis of the fifteen guava samples revealed the absence of detectable pesticide residues. This outcome can be attributed to several factors, including the current practice among guava farmers of using pesticides at lower application rates due to their high cost and limited availability. Furthermore, most guava farmers adopt the practice of bagging fruits at an early stage of development, which contributes to a potential reduction in the need for insecticides. Bagging not only protects the fruits but also minimizes direct exposure to contact-type pesticides. Additionally, a significant number of guava farms categorized as high crop management intensity, particularly large-scale ones exporting to Malaysia, adhere to fruit quality and safety guidelines. This necessitates the application of recommended pesticide levels. According to the survey results, the majority of farmers maintain long pre-harvest intervals, typically lasting two to three weeks. This extended period allows for the gradual degradation of pesticide residues to lower concentrations.

Further, it's also important to note that the absence of detectable pesticide residues does not necessarily imply that the guava is entirely pesticide-free. The lower limit of detection using Gas Chromatography-Mass Spectrometry (GC-MS) is 0.01 mg/kg. Therefore, the pesticide residues content in the samples may be simply too low to be detected by the GC-MS.

C. Fruit Quality

There were no significant differences observed in firmness, titratable acidity, total soluble solid content, average fruit weight, average fruit diameter, and average fruit volume among guava fruits subjected to three different management treatments (at $P<0.05$) (Tab. 1). In conclusion, the study found that crop management intensity had no significant impact on the selected fruit quality parameters.

Several factors may account for the absence of significant differences in fruit qualities within crop management intensity levels, even when different fertilizer and water management conditions were applied. Firstly, the high cost and limited availability of fertilizer during the study period likely discouraged farmers from overusing it. Secondly, many guava farms were established in paddy fields as mixed crops, potentially providing an already established soil fertility advantage. This, in turn, could ensure better moisture conditions for guava due to the inherent water availability in paddy fields. Furthermore, guava farmers' preference for manual weed removal using grass cutters, without removing weed debris from the field, may contribute to the presence of organic matter, which can benefit soil fertility.

In terms of fruit maturity assessment, peel color changes in guava are a key visual indicator. However, the results indicated no significant difference ($P<0.05$) in color values among the three treatments (Tab. 2). This lack of significant difference suggests that all samples were at a similar maturity stage.

TABLE I. AVERAGE FIRMNESS, TITRATABLE ACIDITY, TOTAL SOLUBLE SOLUTES, AVERAGE WEIGHT, FRUIT VOLUME, AND FRUIT DIAMETER OF GUAVA (BANGKOK GIANT) IN DIFFERENT TREATMENTS

Treatment	Average Fruit Firmness (Kg)	Titratable Acidity (Citric Acid %)	Total Soluble Solid Content (Brix^{o})	Average Fruit Weight (g)	Average Fruit Volume (cm^3)	Average Fruit Diameter (mm)
High Management	3.27± 1.07^{a}	0.15±0.02^{a}	9.30±1.16^{a}	0.247±0.02^{a}	195± 14.7^{a}	92.42 ± 2.5^{a}
Medium Management	4.62± 2.20^{a}	0.18± 0.02^{a}	8.59± 1.08^{a}	0.211± 0.03^{a}	199± 26^{a}	85.85 ± 4.2^{a}
Low Management	4.00± 1.07^{a}	0.16± 0.01^{a}	9.87± 1.93^{a}	0.229± 0.01^{a}	195± 22.1^{a}	89.93 ± 1.7^{a}

*Values in the same column with different superscript letters differ significantly (P<0.05).

Each value represents mean + S.D. of five replicates.

TABLE II. COLOR VALUES OF GUAVA (BANGKOK GIANT) IN DIFFERENT TREATMENTS

Treatment	Average Fruit Color Values		
	L* Values	***a* Values***	***b* Values***
High Management Intensity Level	62.77±5.96^{a}	-16.84±0.85^{a}	34.19±0.86^{a}
Medium Management Intensity Level	66.27±2.53^{a}	-15.55±1.43^{a}	35.78±0.62^{a}
Low Management Intensity Level	66.85±2.57^{a}	-15.33±1.14^{a}	35.58±1.79^{a}

Values in the same column with different superscript letters differ significantly (P<0.05) L= 0: black, 100: white; a* = (-): greenness, (+): redness; b* = (-) blueness, (+): yellowness. Each value represents the mean ± S.D. of five replicates.

IV. CONCLUSION

The present study was conducted as a preliminary investigation within limited time constraints and with a restricted sample size to assess pesticide residues and selected fruit qualities in fresh guava. Samples were gathered from the Anuradhapura and Matale districts during the period where ban on the agro-chemicals importation. The crop management intensity was categorized into three levels: high, medium, and low, based on a developed crop management index. The results indicate that guava fruits primarily grown in the Anuradhapura district do not show any significant effects attributable to varying crop management intensities (P<0.05). Additionally, the study suggests that guava consumption is safe in terms of pesticide residue levels. Because the situation (ban on the agro-chemical importation) prevailed during sampling time may be main reasons for this observation. Therefore, it is recommended that a more comprehensive sampling procedure be employed to ensure the representation of major guava- producing areas in Sri Lanka, which would provide a more reliable assessment of the current situation.

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2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

A Comparative Study to Investigate the Changes of Sour Fish Curry Under Modified Atmosphere Packaging with Existing Packaging Methods

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***Abstract*—Sour fish curry, locally known as "Ambul Thiyal," is a traditional and popular dish in Sri Lanka, appreciated for its unique flavor and cultural significance. However, its short shelf life due to the perishable nature of fish and the risk of microbial spoilage restricts its availability and marketability. To address this issue, this research aims to store ambul thiyal in a Modified Atmosphere Packaging (MAP) system that can extend the shelf life of Ambul Thiyal while maintaining or enhancing its product quality in comparison to conventional packaging and vacuumed packaging. A comprehensive experimental setup is conducted to compare the performance of the newly evaluated MAP system with the existing conventional packaging and vacuumed packaging. Both qualitative and quantitative analyses are performed on samples stored in each packaging type, including sensory evaluations, microbial growth assessments, pH levels, and moisture content levels. The results of the study demonstrate that the modified atmosphere packaging successfully extends the shelf life of Ambul Thiyal by retarding microbial growth and reducing oxidative deterioration. Moreover, the sensory evaluations reveal that the product quality is preserved or enhanced under the proposed MAP system when compared to conventional packaging and vacuumed packaging. Sample set 01 was considered as the current conventional package (clay vessels). Samples set 02 was considered as MAP packaged samples. Samples set 03 was considered as vacuumed packaged samples.**

Keywords—Modified-atmosphere-packaging, ambul-thiyal, vacuum packaging

I. Introduction

Sour fish curry, popularly known as "Ambul Thiyal," is a traditional South Asian delicacy cherished for its unique blend of tangy and spicy flavors. The perishability of Sour Fish Curry (Ambul Thiyal) poses a significant challenge to its domestic usage, commercial distribution, and consumer satisfaction. Conventional packaging methods have been insufficient in preserving the Sour fish curry's freshness and sensory attributes, leading to limited shelf life and potential food wastage.

The main objective of this study is to conduct shelf-life studies to evaluate the effectiveness of the MAP in extending the shelf life of sour fish curry, considering factors such as microbial growth, physicochemical attributes such as pH, moisture content, and titratable acidity, sensory attributes like texture, color, odor, flavor, hardness and chemical changes over time.

While MAP has been extensively studied for various perishable food products, there is limited research specifically focused on traditional or ethnic dishes like sour fish curry. To date, there are no studies available for vacuum packaging of Sour Fish Curry. Also, in this study, sensory evaluation analysis, physicochemical analysis, and microbiological analysis were done. MAP parameters like gas composition, packaging material, and temperature that are optimal for preserving the quality and extending the shelf life of sour fish curry.

II. Materials and Method

First, the skip jack tuna fish was washed well and cut into small pieces. Then the fish pieces were washed and cleaned again. Then goraka paste (*Garcinia cambogia*), pepper, curry leaves, and salt were added to the fish. They were mixed together with fish pieces and they were marinated and the pieces were placed in order in the clay pot. It was then cooked on low heat for about an hour until the water is evaporated. The pieces were then kept outside to release the steam before being packed. Samples were prepared according to the recipe mentioned in Tab. 1.

Table 1. Recipe of Sour Fish Curry Used in This Research Study

Recipe - Sour Fish Curry (Ambul Thiyal)		
Ingredients	**Weight (g)**	**Percentage (%)**
Tuna Fish	1000	80
Goraka	125	10
Salt	30	2.4
Pepper	30	2.4
Curry Leaves	15	1.2
Water	250	4

Initially, three sets of samples were arranged. Each set had 7 samples for 21 days. The first sample set had the current conventional package (Clay vessels). The second Sample set had the Modified Atmosphere Package. (30% CO_2 & 70% N_2) [5]. The third Sample set had the vacuum package.

Tests were performed every three days for samples of three sets. After a sample reached a level which is not further acceptable, tests were not continued anymore. pH value, titratable acidity (Eq.1) and moisture content(Eq.2) were measured as the physicochemical measurements.

$$\%Titratable\ Acidity = (N \times V \times k) / w \ldots\ldots\ldots\ldots \quad (1)$$

N = Normality of standard NaOH solution used for titration

V = Volume of standard NaOH used for titration

k = Molecular weight of the predominant acid in the sample divided by the number of hydrogen ions in the acid molecular that are titrated

Acidity was expressed as percent of hydroxy citric acid by weight [2]

w = Weight of the sample

$$Moisture\ Content\ (\%) = ((W1 - W2)/W1) \times 100 \ldots\ldots \quad (2)$$

$W1$ = the initial weight of the food sample before drying.

$W2$ = the weight of the food sample after drying.

Fish Ambul Thiyal samples, stored at room temperature were analyzed for the level of microorganism count by aerobic plate counts (APC) using the ISO 4833-1:2013 method and yeast & mold counts using the ISO 21527:2008 method.

Sensory evaluation was performed every three days for three sample sets. The samples were tested for color, odor, texture, hardness, flavor, and overall acceptance. The tests were carried out by an untrained panel of 10 judges and the samples were evaluated at room temperature. The sensory analysis of Fish Ambul Thiyal was carried out using a nine-point hedonic scale for acceptability to determine the best preservative method. Also, the descriptive analysis was done.

III. Results and Discussion

When measuring the values of physicochemical parameters, the average value of the triplicated samples was applied. Physicochemical testing was performed by every 3 days for sample 01, sample 02 and sample 03. But sample 01 was out of its shelf life on day 03. After day 03, the tests were done only for sample 02 and sample 03. The variation of titratable acidity (Fig. 1), pH value (Fig. 2), moisture content (Fig. 3) mentioned below

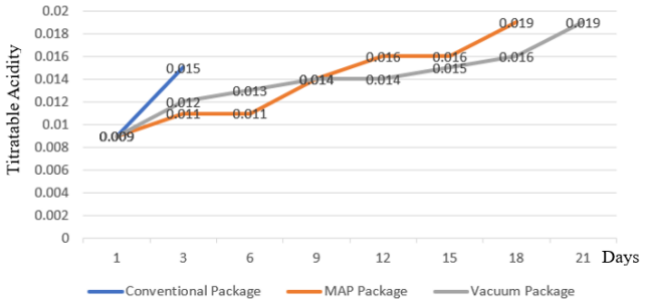

Fig. 1: Titratable acidity variance of three sample sets with the time

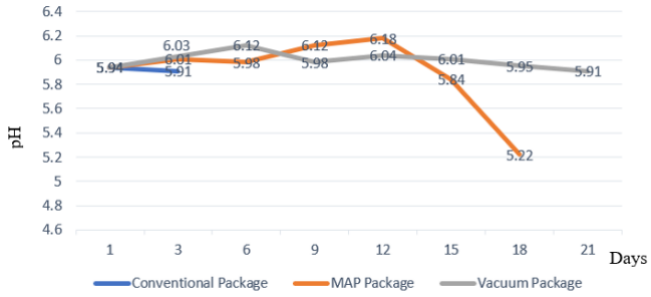

Fig. 2. pH variance of three sample sets with the time

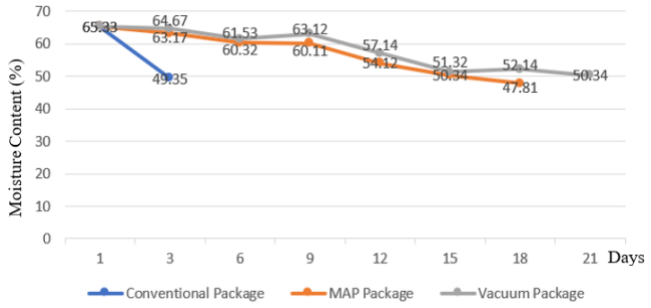

Fig. 3. Moisture content variance of three sample sets with the time

Aerobic Plate Count (APC) and yeast & mold count (Y/M) were determined as microbiological testing for all samples at ambient temperature. The results are mentioned as Colony-Forming Units per Gram of material (cfu/g). The variation of Aerobic Plate Count (Fig. 4) and yeast & mold count (Fig. 5) mentioned below.

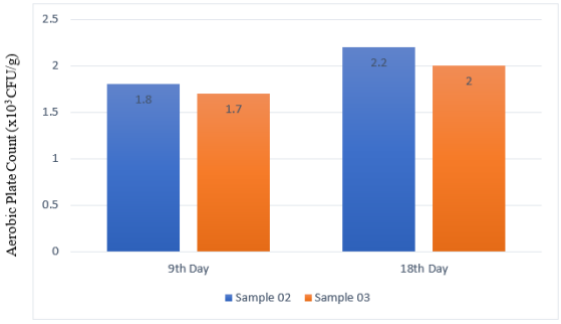

Fig. 4. Aerobic plate count in sample 02 and sample 03 on day 09 and day 18

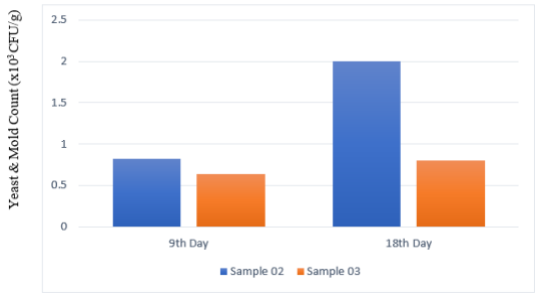

Fig. 5. Yeast and mold count in sample 02 and sample 03 on day 09 and day 18

The color of sample 03 remained intact at 21 days, but sample 02 became not acceptable at 18 days. The color of sample 01 was not acceptable on day 03. the odor of sample

03 remained intact at 21 days, but sample 02 became not acceptable at 18 days. The odor of sample 01 was not acceptable on day 03. The texture of sample 03 remained intact for 21 days. Although sample 02 had not reached not acceptable level within 18 days, the texture P value of sample 02 on day 18 showed a significant difference to the control sample ($P<0.05$). The hardness of sample 03 remained intact for 21 days, but sample 02 was not acceptable on day 18. The hardness of sample 01 had become not acceptable on day 03. The flavor of sample 03 remained intact for 21 days, but sample 02 was not acceptable on day 18. sample 03 had become not acceptable on day 03. The sensory evaluation for flavor was not done for sample 01 on day 03 and sample 02 on day 18. The overall acceptance of sample 03 remained intact in 21 days, but sample 02 became not acceptable on day 18. The overall acceptance of sample 01 had become not acceptable on day 03.

IV. Conclusion

In this study, sample set 01 was considered as the current conventional package (clay vessels). Samples set 02 was considered as MAP packaged samples. Samples set 03 was considered as vacuumed packaged samples. All the samples were kept at ambient temperature. Though the titratable acidity values can be considered overall as an increase with time from the beginning, sample 01 showed a sudden increase while sample 02 and sample 03 showed a slight increment. The pH value of sample 02 showed a higher variance within 18 days, but the pH value of sample 03 showed only a slight variance within 21 days. The pH value of sample 01 reached the not acceptable level with a slight decrease.

Aerobic Plate Count (APC) and yeast & mold count (Y/M) were determined as microbiological testing for all samples at ambient temperature. APC Count and Y&M count of sample 02 were higher than sample 03 on day 09 and day 18.

Therefore, the conclusion of sensory evaluation was for Sample 03, every sensory parameter is at an acceptable level in 21 days. But in sample 02, every sensory parameter is at an acceptable level for 15 to 18 days. Sample 01 every sensory parameter is at an acceptable level for 1-3 days. Considering all the above facts, sour fish curry (Ambul Thiyal) in the vacuumed package can be kept for a longer time. Compared with the vacuumed package, the MAP package can be kept for a little less time. Both the vacuumed packaged and MAP packaged samples can be kept longer time compared to the current conventional package.

Acknowledgement

The authors are extremely grateful towards Dr. Deepika Priyadarshani, the lead of Biosystems Engineering at the Sri Lanka Technological Campus, Mrs. Dinusha Kariyawasam and Mrs. Mishenki Rajapakse, Lecturers of SLTC Research University for their guidance and support extended. I would like to give special thanks to Mr. Bandula Fernando, Quality Assurance Officer at Industrial Gases (Pvt) Ltd, and Mr. Nisala Gunasekara, Research Officer at Industrial Technology Institute for his assistance and resources, for the kind support to success this research period.

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2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

Forest Fire Prediction Models in Portugal: A Comprehensive Review

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***Abstract*—Amid increasing forest fire threats in Europe, particularly the Mediterranean, Portugal stands out due to its disproportionately high wildfire incidents. The 2017 wildfire season alone consumed 6% of the Portuguese territory, highlighting an urgent call for effective solutions. While the National Lookout Towers Network (NLTN) is pivotal in fire prediction in Portugal, it covers only 31% of the mainland with single tower arrangements, leaving significant areas, including 17% designated as high-priority, vulnerable. This paper reviews various forest fire prediction models tailored for Portugal, including machine learning and other methodologies. The inherent challenges in these models include skewed data distribution, feature selection optimization, and overfitting. Prospective enhancements suggest integrating diverse data and ensuring adaptability to Mediterranean regions. The forest fire simulation modeling approach presented in this study holds significant potential for broader applications in the context of forest fire management in fire-prone regions, thereby offering valuable insights into addressing this pressing issue.**

Keywords—Forest fires prediction model, machine learning, Portugal

I. INTRODUCTION

Forests, those sprawling and verdant expanses dominated by majestic trees and a rich tapestry of vegetation, play an indispensable role in our lives. They provide sustenance, shelter, clothing, and even the air we breathe, serving as an abundant source of life-sustaining oxygen [5]. Despite their vital contributions, these woodlands are fragile in the face of a global threat which is defined as forest fires. Once ignited, forest fires can cause significant harm to the environment, economy, and society. Recent years have witnessed the tragic loss of numerous species, escalating soil erosion, and the stark depletion of lush vegetation, resulting in damaged terrain. The undeniable adverse effects on infrastructure and property resulting from these conflagrations have left communities contending with the aftermath of devastation. The intricate relationship between fire and forests is a crucial part of our planet's carbon cycle, influenced by weather conditions, flammable materials, and human actions [6]. This has far-reaching consequences, from harming the environment and economies to endangering human lives [1]. Human health is at risk due to the smoke, which worsens respiratory and heart problems, causing suffering in its wake [5].

Various studies have explored the evolution and geographical spread of wildfires over time, revealing a troubling pattern [1]. In recent decades, Europe has witnessed a marked increase in wildfires, particularly in the Mediterranean region, where environmental conditions favor their occurrence [11]. Despite its smaller size compared to other Mediterranean nations, Portugal has been severely affected by these wildfires [7]. Mainland Portugal spans 18 districts across 90,000 square kilometers in southwestern continental Europe on the Iberian Peninsula, situated between 37° N and 42° N latitude and 6° W to 10° W longitude. Its landscape is diverse, featuring rugged mountains in the north and flat or gently rolling terrain in the south, as illustrated in Figure 1. Portugal experiences a Mediterranean climate with wet winters and hot, dry summers. The duration of the dry season increases as one moves southward and inland [8].

Unmanned Aerial Vehicles (UAVs) can be used in the detection and monitoring of forest fires, with a particular focus on the diverse landscapes of Portugal. Portugal, characterized by its extensive forested areas, has historically been vulnerable to devastating forest fires, emphasizing the need for innovative and effective fire detection methods. UAVs, equipped with advanced sensors and imaging technologies, offer a promising solution. They provide real-time data and high-resolution imagery, crucial for early fire detection and the assessment of fire behavior. By analyzing case studies from recent forest fires in Portugal, such as the tragic 2017 Pedrógão Grande fire, this paper will demonstrate how UAVs can significantly enhance fire detection capabilities. The integration of UAVs not only

aids in rapid response but also in the strategic allocation of firefighting resources, potentially mitigating the impact of such disasters. This study aims to contribute to the growing body of research on UAV applications in environmental monitoring, specifically in the context of forest fire management and prevention [19].

While some other Southern European countries are taking different approaches, Portugal has been grappling with a consistent increase in forest fires and the resultant expansion of burned land. Despite increased investments in fire prevention and suppression, approximately 25% of Portugal's land was scorched between 1990 and 2005. The years 2003 and 2005 witnessed particularly devastating fires, affecting an estimated 750,000 hectares [1]. Moreover, in the 2017 wildfire season in Portugal, an unprecedented 6% of the country's land was devoured by flames, underscoring the pressing need for a long-term solution. This dire situation was exacerbated by extreme fire weather conditions, characterized by high Fire Weather Index (FWI) values, wind speeds exceeding 25 km/h, and critically low 1-hour fuel moisture content. These conditions resulted in rapid fire spread rates, including peaks of 4,000 hectares per hour during the Pedrógão Grande fire. What makes matters more challenging is that many of these large fires occurred in close proximity to rural communities with aging populations, limiting their capacity to respond to such severe wildfires [4]. This places Portugal among the most fire-prone countries in Southern Europe. Therefore, this paper aims to provide an overview of the current state of fire prediction in Portugal and to present the developed fire prediction models specific to Portugal which are available in the literature. Data has been gathered from published research studies previously to prepare a comprehensive analysis of the forest fire prediction status of Portugal at present and to suggest improvements for forest fire prediction and mitigation in Portugal which has been identified as one of the victimized countries from forest fires globally.

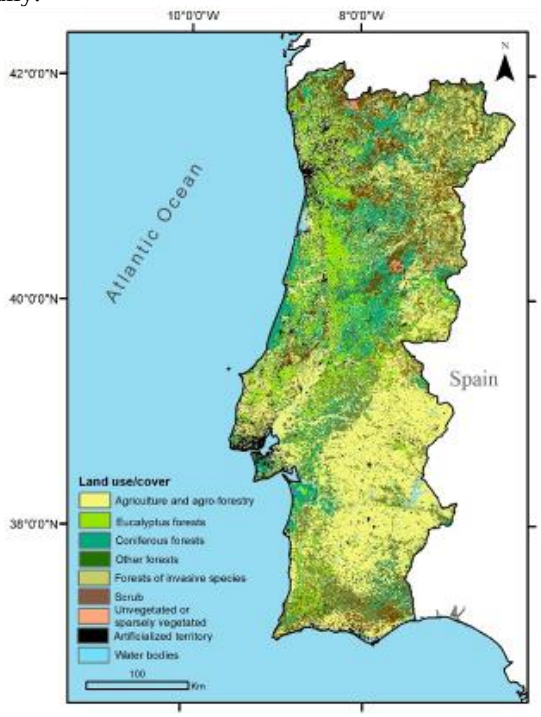

Fig. 1 : Variation of altitude in Mainland Portugal (Source : [3])

II. Forest Fire Prediction in Portugal

In recent years, the importance of forest fire prediction, prevention, and management strategies has significantly increased [10]. The development of systems for forecasting forest fire risks has become a crucial tool for assessing the likelihood of forest fires. Furthermore, predicting the geographical areas where fires are likely to start proves invaluable for forest managers, enhancing the efficiency of resource allocation for fire prevention, detection, and firefighting efforts [11]. These systems not only assist in evaluating the risk of forest fires but also play a pivotal role in supporting ongoing monitoring and suppression efforts during fire outbreaks. Additionally, they contribute to the strategic planning of fire control measures and the efficient allocation of resources for fire management. Portugal distinguishes itself among Southern European countries due to its alarming frequency of wildfire ignitions, underscoring the need for a concerted effort to predict the spatial distribution of these ignitions. This predictive capability holds immense significance for effective fire management, as it enhances the allocation of resources for prevention, detection, and firefighting, a perspective shared by experts [11]. The urgency in developing this forecasting tool arises from the multifaceted impact of forest fires, which cause economic and ecological damage while endangering human lives. Timely detection emerges as a pivotal factor in mitigating these consequences, necessitating agile and efficient fire management strategies [7].

The Ministry of Agriculture and Rural Development in Portugal (Ministério da Agricultura e do Desenvolvimento Rural) is instrumental in the management of forest fires by establishing policies and regulations, promoting fire prevention and safe forest management, providing resources for firefighting, and collaborating with various stakeholders to reduce fire risk and enhance the country's ability to respond to forest fire emergencies. Further, In Portugal, fire prediction and management are critical areas overseen by several institutions e.i. Institute for the Conservation of Nature and Forests (Instituto da Conservação da Natureza e das Florestas (ICNF)), National Authority for Civil Protection (Autoridade Nacional de Emergência e Proteção Civil (ANEPC)), Portuguese Institute for the Sea and the Atmosphere (Instituto Português do Mar e da Atmosfera (IPMA)), Higher Institute of Agronomy (Instituto Superior de Agronomia (ISA)), Forest Technical Office Gabinete Técnico Florestal (GTF)), Institute of Agrarian Development and Forestry (Instituto de Desenvolvimento Agrário e Florestal - IDAF).

The Institute for the Conservation of Nature and Forests is responsible for the management and conservation of natural resources in Portugal, including forests. They play a vital role in wildfire prevention through forest management and regulations. The National Authority for Civil Protection is responsible for coordinating and managing emergency responses, including wildfires. They play a central role in organizing resources and actions during wildfire events. The Portuguese Institute for the Sea and the Atmosphere is responsible for monitoring weather conditions and providing early warnings for extreme events, including fire weather

forecasts. The Higher Institute of Agronomy is a leading academic institution in Portugal with expertise in forestry and environmental sciences. They contribute to research and education in fire prediction and management. The National Command for Emergency Operations is responsible for coordinating responses to various emergencies, including forest fires. The Forest Technical Office operates at the municipal level and works on fire prevention strategies, including land management and local community engagement. The Institute of Agrarian Development and Forestry in Portugal contributes to the prevention and management of forest fires by conducting research, implementing forest management practices, enforcing regulations, and coordinating with other agencies and stakeholders. They play a crucial role in reducing the risk of forest fires and ensuring a prompt and effective response when wildfires do occur. These institutions collaborate to monitor, predict, and manage wildfires in Portugal, aiming to mitigate their impact on the environment and communities.

In Portugal, the primary fire detection system is the National Lookout Towers Network (NLTN). However, its effectiveness and coverage have been subject to limited exploration. Recent assessments have revealed that 28% of mainland Portugal lacks NLTN coverage, while 31% relies on a single lookout tower, which is insufficient for adequate fire detection. Approximately 17% of the territory represents high-priority areas for fire surveillance due to poor lookout visibility and high fire risk. However, despite regional variations, there is a relatively low percentage of initial fire detections made by lookout towers, and this percentage seems to be on a decline [2]. To prevent large-scale wildfires, the effectiveness of preventive measures, vigilance, and rapid response operations is of utmost importance. However, the success of these efforts depends heavily on early detection. Given the costliness and subjectivity of traditional human surveillance, there is a concerted effort to adopt automated solutions. Recognizing the pivotal role of fire detection systems in minimizing losses, it is essential to comprehensively evaluate their operational efficiency to optimize resource allocation [12].

At the heart of Portugal's historical landscape lie wildfires that have shaped the nation's terrain. However, contemporary times have witnessed a surge in large wildfires, causing severe degradation in substantial areas of the country. These extensive blazes, spanning over 100 hectares each, serve as a stark reminder of the pressing need for innovative strategies to address this ecological crisis [9]. As Portugal struggles with the evolving fire scenario, understanding the intricacies of ignition patterns, detection systems, and the changing fire landscape remains imperative for preserving both the environment and the inhabitants it shelters.

III. Reported Fire Prediction Models Developed for Portuga

Numerous fire prediction models have been developed for forecasting fires in Portugal, and these studies have been summarized as follows (Table 1). A significant portion of these models fall into the category of machine learning-based fire prediction models. They encompass both supervised and unsupervised machine learning techniques in their model development. Furthermore, while some models were designed to provide predictions for the entire nation of Portugal, others are specifically tailored to address fire predictions in particular regions of the country.

A. Machine Learning Based Models

Based on the forest fire data, a forest fire prediction model for the Northern region of Portugal was developed using machine learning techniques, including Multiple Regression (MR), Decision Trees (DT), Random Forests (RF), Neural Networks (NN), and Support Vector Machines (SVM). The model incorporated various variables, such as spatial, temporal, Fire Weather Index (FWI) components (an indicator of fire intensity), and weather attributes (temperature, relative humidity, rain, and wind speed). After rigorous evaluation, the SVM model with four direct weather inputs (i.e., temperature, rain, relative humidity, and wind speed) was identified as the best configuration. This model demonstrates proficiency in predicting small fires but exhibits lower accuracy in forecasting large fires. Notably, this represents the first instance where burn area prediction is solely based on meteorological data. Furthermore, parameters like vegetation type and firefighting interventions such as time elapsed and firefighting strategy can be incorporated to enhance the model's accuracy [7].

In parallel, a Support Vector Method (SVM) model was introduced using recent real-world data collected from the northeast of Portugal by [15]. Parallel SVM considers the Forecast Weather Index (FWI) and some weather parameters for the prediction of a forest fire and the parallel SVM model reduces the computational time and high storage required for the analysis. In the Portugal dataset, the parallel SVM model demonstrates a RMSE of 63.45, while the conventional SVM method yields an RMSE of 63.5. Therefore, developed models from conventional methods show a higher accuracy comparatively.

By the way, the study in [1] encompassed various Machine Learning approaches, such as extreme gradient boosting (XGBoost), random forest (RF), support vector machine (SVM), and decision tree (DT). This research was conducted using data from Montesinho Natural Park, with a monthly dataset spanning from January 2000 to December 2003. The data was categorized into two sets, distinguishing between flammable and non-flammable areas using the K-means++ clustering technique. For the variables, including X and Y coordinates, FFMC, DMC, DC, ISI, temperature, relative humidity (RH), wind, and rainfall, the XGBoost model exhibited superior performance, as evidenced by three evaluation metrics (ACC = 0.8132, F1 = 0.7862, and AUC = 0.8052). Furthermore, it's worth noting that the ACC, F1, and AUC values are higher in machine learning models based on spatiotemporal characteristics rather than models classifying wildfires by their burned area size, indicating that spatiotemporal heterogeneity has a significant impact on wildfire occurrence. Even though this [1] reveals that XGBoost model performed well than SVM,

RF, DT the duration of dataset is limited in here compared to the study [7] and [15].

On the other hand, regression models also performed well according to the following studies. In a separate study, reference [11] developed a model utilizing the logistic regression method, encompassing the entire mainland of Portugal. This model utilized forest fire data from the period 2001-2005, sourced from the Portuguese Forest Services. The variables considered in this model included population density, human accessibility, land cover, and elevation. Analysis of the receiver operating characteristic curve (ROC) curve reveals that 87.2% concordance between predicted probabilities and observed outcomes while with the confusion matrix method achieved a global accuracy of 80.3%. This model underscores that human presence and activity serve as the primary drivers of fire ignitions in Portugal, with population density emerging as the most significant contributing factor. Notably, the majority of ignitions (85%) were concentrated in areas characterized by a blend of agriculture and urban-rural elements, whereas only 15% occurred in forested or uncultivated areas, despite the latter covering half of the country's land area. Agriculture stands out as a prominent factor influencing the initiation of fires, while forests, shrublands, and sparsely vegetated areas also exhibited a positive influence on ignition occurrence, though their impact was comparatively lower.

Another machine learning model, based on Extreme Learning Machines (ELM), was implemented and compared with Linear Regression, Random Forest Regression, and Support Vector Regression (SVR) methods. The dataset for this study was sourced from Montenshino Natural Park in Portugal and comprised a total of 517 forest fire incidents. This dataset encompassed 13 attributes and 517 data entries, with features including variables such as X, Y, month, day, FFMC (fine fuel moisture code), DMC (duff moisture code), DC (drought code), ISI (initial spread index), temperature, relative humidity (RH), wind, and rainfall. In this study, the ELM method produced an RMSE (Root Mean Square Error) value of 63.09511. The results of this comparison indicate that the ELM method can yield outcomes that are competitive with the Linear Regression method. Furthermore, it can be inferred that, when working with this dataset, the most effective methods for addressing forest fire prediction cases are Linear Regression and ELM [13]. Fire prediction using linear regression, ridge regression, and lasso regression was done in [14]. It is based on Montesinos park and climate, and physical factors were considered as variables. The accuracy of the linear regression algorithm gives higher accuracy than ridge regression and lasso regression algorithms.

Three regression models were developed in reference [3] and each model is developed using different independent variables: one using only susceptibility (Susc), another using only the absolute values of Seasonal Severity Rating (SSRAbs), and the third using both Susc and SSRAbs. These models were applied to analyze the annual burnt areas of Mainland Portugal over a 24-year period, from 1995 to 2018. The data was sourced in vector format from the Portuguese Institute for Nature Conservation and Forests (ICNF), with key parameters including slope, elevation, and land cover. When combining the index with wildfire susceptibility, there was a slight increase in the model's capability to predict areas that would burn, compared to using susceptibility alone. The spring meteorological context was found to be more suitable for predicting the severity of the upcoming summer wildfire season, rather than pinpointing the specific locations of wildfires. The highest Likelihood Ratio was observed in the elevation class of 1000m-1500m (LR-3.2786), with slope angles less than 20º (LR-2.5817), and in areas with sparse vegetation (LR-3.6347). The authors also proposed that the model could be updated annually following the critical wildfire season and applied to optimize the allocation of human and material resources for prevention, early detection, and suppression activities, all aimed at reducing the severity of wildfires in the country.

Conversely, a Sparse Autoencoder-based deep neural network, coupled with an innovative data balancing procedure involving Artificial Neural Networks (ANN), Support Vector Machines (SVM), and Random Forest (RF), was implemented using forest fire data collected between 2000 and 2003 from Portugal's Montesinho Natural Park, comprising a total of 517 records [16]. This proposed method exhibits superior accuracy in predicting large-scale forest fires. This approach holds the potential to significantly enhance wildland fire management and preclude serious fire accidents. However, constructing prediction models can be challenging due to the need for selecting the most relevant features for the prediction task and handling the substantial imbalance in data distribution, where the number of large-scale forest fires is notably lower than that of small-scale incidents.

Moreover, a combination of remote sensing techniques and machine learning (specifically, Random Forest) supported forest fire prediction. The study utilized Landsat surface reflectance (SR) data for Northwest Portugal, featuring a resolution of 30 meters (level 2, collection 2, tier 1) spanning from 2001 to 2020 [9]. The results revealed that, based on the derived burnt area maps, approximately 23.5% of the territory experienced at least one fire event between 2001 and 2020. The temporal analysis of burnt areas indicated an average impact of 6,504 hectares within the 20-year timeframe. Annual burnt area figures exhibited variability, with the lowest recorded in 2014 (679.5 hectares) and the highest mapped area observed in 2005 (73,025.1 hectares). Therefore, SVM and Regression models outperform than the other models while most of them are suitable for large-scale fires only. Also, anthropogenic factors have a higher impact on forest fires similar as the weather inputs.

B. Other Models

An evaluation of the National Lookout Towers Network (NLTN) using Geographic Information Systems (GIS) was conducted in a study by [2]. This evaluation encompassed the entire mainland of Portugal. The results of this assessment indicate that the National Lookout Towers Network plays a crucial role in fire detection in specific

regions of Portugal. However, in other regions, its effectiveness in detecting wildfires is notably limited, accounting for only a small percentage of total wildfires.

Also, NLNT is more efficient during the day than other detection systems, but less efficient at night. At least about 34% of the Portuguese mainland has a very low or low probability of a fire being detected by lookouts, and 17% of the territory has high priority in terms of complementary fire vigilance, due to its high fire risk and low NLNT vigilance. The areas where additional fire vigilance is more necessary, complementarily to the NLTN system were identified. Relation between the estimated visibility or detection probability and the percentage of wildfires effectively detected by the NLNT system between 2001 and 2003 and verified very good adjustments (R^2 = 0.97 to R^2 = 0.88).

In reference [8], which focused on the Portuguese mainland and examined records spanning from 1996 to 2015, drawn from the Portuguese Institute for Nature and Forests Conservation (ICNF) database, relevant validated statistics reveal that out of the total recorded fire events, 94.4% were confirmed as actual occurrences. Among these, 22.2% had burned an area exceeding 1 hectare, and of these, only 42.1% were thoroughly investigated. Notably, false alarms or fires without a recorded burning area were more prevalent in the districts of Aveiro, Lisbon, and Porto, which are the largest municipalities. When examining the causes of investigated fires, it was observed that the majority of recorded events occurred in the northeastern regions (49.0%), followed by the northwestern regions (41.7%), with the rest of the country accounting for 9.3%. A more in-depth analysis, considering the ratio between investigated fires and the total number of fires, provided a different perspective, with the central and southern regions showing more diligence in investigating fires. A comprehensive analysis of the causes and motivations behind the ignition of these forest fire incidents revealed that human activity, whether deliberate (20.4%) or negligent (29.9%), surpassed natural phenomena (0.6%). Over time, reactivations (14.6%) and unknown (34.5%) causes decreased, while negligent and deliberate causes increased.

Minimum Travel Time algorithm was employed in [4], incorporating variables such as wildfire season winds (speed and direction), frequency scenarios, and fuel moisture content. The study revealed that 10,394 structures were exposed to fire each year, with 30% of communities accounting for 82% of this total. The predicted burned area in natural sites amounted to 18,257 hectares annually, of which 9.8% was located in protected land where fuel management is not permitted. Notably, the primary burn probability hotspots were identified in the central and northern regions. This study underlines critical priorities for safeguarding the most vulnerable communities and promoting national-level landscape management programs. Moreover, this research is valuable in informing Portugal's new national plan, currently in implementation, which relies on a probabilistic methodology for decision-making. In terms of future directions, the wildfire simulation modeling approach presented in this study can be extended to other fire-prone Mediterranean regions, where predicting catastrophic fires can play a crucial role in anticipating and mitigating future disasters.

Fuel Breakdown Network (FBN) has been developed in [17]. Data on residential buildings were acquired as spatial points from the Instituto Nacional de Estatistica, and input data for the wildfire simulation modeling library were sourced from a previous study. Regarding the planned Fuel Breakdown Network (FBN), the results indicated the potential for reducing the annual burned area from large fires by up to 13% (equivalent to approximately 13,000 hectares), cutting the annual number of exposed residential buildings by up to 8% (around 100 residential buildings), and decreasing the annual burned area in protected areas by up to 14% (approximately 2,400 hectares). The expected burn-over percentage varied considerably across different segments in response to estimated fire intensity, resulting in an average decrease of 40% in overall effectiveness. Notably, the most critical fuel breaks exhibited a higher percentage of fire burn-over and, consequently, a reduced level of effectiveness. Additionally, it was revealed that the current implementation of the FBN follows a random sequence, which is suboptimal for achieving all objectives.

Susceptibility models were developed for mainland Portugal using the Likelihood Ratio method[18]. The input dataset consisted of burned areas over 44 years, along with a set of predisposing factors related to topography and land cover. The results of this study highlight areas where the combination of terrain features is more favorable for fire propagation. Notably, the highest favorability scores were associated with shrubland-type vegetation, while agricultural areas, cork, and holm forests exhibited lower scores. Eucalyptus and maritime pine forests displayed intermediate scores, and their presence has increased since 2007. The two highest hazard classes correctly classified 90% of the burned area over 44 years, underscoring the model's high accuracy. If these hazard classifications are integrated into spatial planning instruments, in conjunction with municipal plans, they can potentially restrain the expansion of built-up areas. It's noteworthy that approximately 2% of municipalities have over 90% of their territory classified as hazardous, whereas 32% of municipalities have less than 10% of their area falling into the hazardous category. These structural maps provide a valuable foundation for a long-term approach and can be supplemented with estimations regarding the behavior and severity of wildfires, which warrants further exploration.

IV. Limitations and Challenges

In the domain of forest fire prediction for Portugal, there are significant challenges and limitations. Existing predictive methods, such as the Cascade Correlation Network (CCN), Radial Basis Function (RBF), and Support Vector Machine (SVM), have demonstrated their limitations in addressing the intricate dynamics of forest fires. They often suffer from overfitting issues and reduced predictive accuracy, particularly when dealing with large fires [7], [15]. While the conventional SVM excels at predicting small fires, it struggles to provide accurate forecasts for large-scale fires [15]. These challenges are further

compounded by the inherent difficulty in constructing prediction models. This difficulty stems from the twin challenges of selecting the most relevant features for prediction [16] and contending with a data distribution that is heavily skewed toward small-scale fires. This skewed distribution results in a disproportionate scarcity of information on large-scale forest fires [16].

V. Recommendations and Future Directions

Looking forward, the forest fire prediction models in Portugal have room for refinement and expansion. Beyond the scope of this study, the incorporation of critical details such as vegetation types and specific firefighting interventions, including factors like elapsed time and employed strategies, holds the potential to enhance predictive accuracy [7]. To drive continuous improvement, an effective strategy involves regular model updates following the critical wildfire season. By aligning resource allocation with insights into prevention, early detection, and suppression strategies, the severity of wildfires could be mitigated [3]. As we move into the future, the wildfire simulation modeling approach introduced here offers promise for broader applications. Its adaptability to other fire-prone Mediterranean regions presents the opportunity for early disaster anticipation and effective management [4]. The exploration of a maximum entropy model customized to Portugal's specific context represents an open pathway, providing opportunities to improve forest fire management and disaster preparedness [18].

VI. Conclusion

Within the European context, Portugal, despite its smaller geographical stature, has encountered a pronounced escalation in wildfire incidents, resulting in substantial areas of charred land. This trend underscores the critical importance of forest fire prediction, prevention, and comprehensive management strategies. A precise prediction of fire ignition locations is fundamental for the judicious deployment of resources and heightened firefighting efficacy. While Portugal's National Lookout Towers Network serves as the primary means for fire detection, it exhibits certain constraints. As timely detection becomes increasingly imperative to prevent expansive wildfires, there's an emerging emphasis on integrating automated tools alongside human-operated systems. A series of advanced machine learning-driven fire prediction models have been introduced. These models, which factor in meteorological conditions, fuel moisture levels, and historical patterns, aim to predict forest fire susceptibilities and refine preventive measures.

Efforts to enhance forest fire prediction models in Portugal face challenges such as overfitting and a tendency to focus on minor fires. Addressing these requires a comprehensive approach that includes varied vegetation types and updated firefighting methods. Regular model updates following major fires are crucial for better resource distribution. The progress made in Portugal's fire prediction models is not only vital for the country, given its high incidence of wildfires, but also offers a framework that could be adapted in other fire-prone areas. Improving these models is key to reducing the ecological and community impact of forest fires, particularly in Southern European regions.

Acknowledgment

This work was supported in part by the COFAC - Cooperativa de Formação e Animação Cultural, C via the project AOEE-WiPS (COFAC/ILIND/COPELABS/2/2022), by the national funds through FCT - Fundação para a Ciência e a Tecnologia - as part the project AIEE-UAV (no. 2022. 03897.PTDC) and COPELABS (no. UIDB / 04111/2020).

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TABLE 1. SUMMARY OF FIRE PREDICTION MODELS FOR PORTUGAL

Model/Method Used	Data Source	Variables/Features	Model Performance	Key Findings	Limitations & Challenges	Recommendations & Future Directions	Reference
MR, DT, RF, NN, SVM	Northeast region of Portugal.	Spatial, temporal, FWI components, weather attributes	SVM with weather inputs best for small fires.	Meteorological data used for predicting burn area.	Lower accuracy for large fires.	Consider additional information like vegetation type and firefighting intervention for large fires.	[7]
Logistic Regression	Entire Portuguese mainland	Population density, human accessibility, land cover, elevation	Good predictive ability with ROC concordance of 87.2%.	Human presence/activity key drivers of ignitions.	Limited to a specific time period.	Incorporate more recent data and explore other factors influencing ignitions.	[11]
ELM, Linear Regression, RF, SVR	Montenshino Natural Park, Portugal	X, Y, month, day, FFMC, DMC, DC, ISI, temp, RH, wind, rain	ELM with 20 hidden neurons and Linear Regression best.	ELM competitive with Linear Regression.	Data imbalance for small and large-scale fires.	Address data imbalance and optimize for large-scale fire prediction.	[13]
Linear Regression, Ridge, Lasso	Montesinos park, Portugal	Climate and physical factors	Linear Regression showed higher accuracy.	Linear Regression outperformed Ridge and Lasso.	Limited to specific location.	Test on diverse geographic regions and consider more factors.	[14]
Regression models	Mainland Portugal, 1995-2018	Slope, elevation, land cover	Combination of Susc and SSRAbs improved prediction.	Spring meteorological context important.	Update model yearly post-critical wildfire season.	Integrate into spatial planning instruments.	[3]
Parallel SVM	Northeast Portugal	FWI, weather parameters	Parallel SVM reduced computational time.	Reduced computational burden.	Slight reduction in RMSE.	Further optimize computational efficiency.	[15]
XGBoost, RF, SVM, DT	Montesinho Natural Park, 2000-2003	X, Y, FFMC, DMC, DC, ISI, temp, RH, wind, rain	XGBoost performed best with spatiotemporal characteristics.	Spatiotemporal models outperformed area-based models.	Limited to a specific time period.	Consider temporal dynamics for larger prediction windows.	[1]
Sparse autoencoder-based DNN	Montesinho Natural Park, 2000-2003	Various meteorological variables	Improved prediction of large-scale forest fires.	Reduced prediction errors.	Data imbalance for small-scale fires.	Explore feature selection techniques and address data imbalance.	[16]
Random Forest with time series	Northwest Portugal, 2001-2020	Landsat surface reflectance data	23.5% territory burnt; annual burnt area varies.	Temporal variability in burnt area.	Focus on specific region.	Expand analysis to other regions and explore long-term trends.	[9]
Evaluation of National Lookout Towers Network (NLTN) using GIS	Entire Portuguese mainland	Lookout towers' efficiency	NLTN efficient in some regions, less at night.	34% of mainland not well covered by NLTN.	Inefficient at night.	Improve NLTN coverage and nighttime detection.	[2]
Cluster Analysis	Portuguese mainland, 1996-2015	Causes and motivations of forest fires	Human activity major cause.	Regional differences in fire investigations.	Limited to specific time frame.	Analyze trends over time and across regions.	[8]
Minimum Travel Time Algorithm	National wildfire season data	Wildfire winds, frequency scenarios, fuel moisture content	Priorities for safeguarding communities.	Predicted burned area and community exposure.	Specific to wildfire seasons.	Incorporate real-time data for proactive measures.	[4]
Fuel Breakdown Network (FBN)	Mainland Portugal	Residential buildings data, wildfire simulation	Potential reduction in annual burned area and residential buildings exposed.	Effectiveness of fuel breaks varies.	Suboptimal implementation sequence.	Optimize fuel break strategies and implementation.	[17]
Susceptibility models using Likelihood Ratio method	Mainland Portugal	Burned area data, topography, land cover	High accuracy in hazard classification.	Favorability scores for different vegetation types.	Long-term approach needed.	Integrate into spatial planning instruments.	[18]

2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

Assessing the Ecological and Socio-economic Impacts of Waste Disposal and Management in Muthurajawela Wetland: A Case Study

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Abstract*—Muthurajawela, a unique coastal wetland in Sri Lanka, faces numerous social and environmental challenges. Uncontrolled land development and environmental pollution in Muthurajawela have disrupted its delicate ecological balance. In preceding inquiries, no relevant data of this particular matter have been discerned. Consequently, this study, conducted within the Bopitiya East Grama Niladari Division of Kerawalapitiya City in the Muthurajawela region, employed a comprehensive approach involving questionnaires, interviews, and on-site observations. The purpose was to methodically scrutinize the ecological and socio-economic ramifications linked to waste disposal and management in the wetland area. A random sample of 50 participants was chosen, and the questionnaires aimed to gather data on waste dumping awareness, environmental impact, health and social consequences, control measures, and restoration efforts in Muthurajawela marsh. A significant 58% of the surveyed population identified soil pollution as a concern, while an overwhelming 94% pointed to water pollution as the primary issue. Additionally, 24% of respondents acknowledged air pollution, 13% cited harm to wildlife, and 12% expressed concerns regarding the degradation of wetland ecosystems. The study investigated smokestack emissions' contribution to environmental contamination. 96% of respondents observed alterations in the quality of their well water. It emphasizes that a significant majority, 90%, expressed concerns about negative health effects. 80% of respondents affirmed the reduction of property values. Waste disposal was confirmed to result in flooding during heavy rainfall by 96% of the respondents. A majority, 78% of the respondents, indicated they had taken action against the waste dump in their area. To tackle environmental problems in Muthurajawela, it's essential to emphasize responsible waste management, implement pollution control measures, and foster collaborative partnerships among local communities, businesses, and government entities.

Keywords—Socioeconomic, ecological, environmental hazards, waste disposal, Muthurajawela

I. INTRODUCTION

Muthurajawela is a unique and ecologically significant wetland ecosystem located in Sri Lanka, specifically in the western region of the country, which is close to the city of Colombo. Located on Sri Lanka's western coast, close to the Indian Ocean. Muthurajawela has a total size of about 2,400 hectares. Just to the north of the Colombo metropolitan region, it is situated strategically. Due to its historical importance and abundant biodiversity, it is frequently referred to as the "Swamp of Royal Treasure". As one of Sri Lanka's major saltwater wetlands, Muthurajawela has been recognized a Ramsar Wetland of International Importance, emphasizing its global ecological significance. Further, Muthurajawela is well known for having a diverse ecosystem. Numerous types of fish, birds, amphibians, reptiles, and mammals live there, as well as a large variety of other plants and animals. Eco-tourists and lovers of nature go to Muthurajawela because of its distinct

attractiveness. Muthurajawela is an important asset for Sri Lanka because it offers crucial ecosystem functions [1]. Within the Muthurajawela industrial zone, in close proximity to the Bopitiya area, prominent features include the Yugadanavi Power Station and the Kerawalapitiya waste disposal plant. Additionally, some industries like Sobadhanavi Power plant and Pyramid Lanka (Pvt) Ltd can be found. Yugadanavi Power Station is a combined cycle power plant that has a capacity of 300MW and is powered by oil [2]. Furthermore, a 10 MW power plant, which commenced operations in 2021 in Muthurajawela, is equipped to process a daily capacity of up to 700 metrics tonnes of municipal solid waste. Kerawalapitiya waste disposal plant has initiated a program to increase the amount of bio-organic compost produced at the Kerawalapitiya solid waste management park from 15 metric tons (MT) per day to 50 MT per day, according to the Ministry of Urban Development and Housing [3].

Rapid industrialization and urbanization in the area have sparked concerns about their sustainability and potential effects on the delicate balance of the marsh. The ecological importance and rich biodiversity of Muthurajawela are under threat from waste disposal and industrial expansion. This survey is rooted in the urgent need to address environmental concerns within the delicate ecosystem of Muthurajawela, Sri Lanka. One concerning aspect of this research is the existence of waste disposal sites within the confines of Muthurajawela. These sites function as facilities for the disposal of different types of waste. Understanding how such dumping affects the ecology is crucial since it might seriously endanger this ecosystem. These locations have the potential to contaminate the soil and water, polluting the ecosystem and releasing poisons. The local flora and animals may be adversely affected by this contamination, which may change their habitats and may cause a reduction in biodiversity. Additionally, the contaminants leaking into water bodies can harm aquatic ecosystems. The presence of smokestacks in industries within Muthurajawela represents a critical aspect of our research focus. These smokestacks serve as a symbol of industrial activity and are essential to understanding the regional environmental dynamics. These enormous towers emit a variety of pollutants into the atmosphere, which could affect the fragile balance of the Muthurajawela ecosystem [4]. This study is a survey investigation into the environmental problems that a part of Muthurajawela wetland ecosystem in Sri Lanka is currently dealing with [5]. It includes two essential elements: the existence of waste disposal sites nearby and emissions from nearby industrial smokestacks.

II. MATERIALS AND METHOD

A. Study Area

The study was conducted in Muthurajawela-filled land. It is located at Bopitiya East Grama Niladari Division, Kerawalapitiya city, north of the Colombo metropolitan region, western cost of Sri Lanka (79°51'43"E, 7°01'42"N).

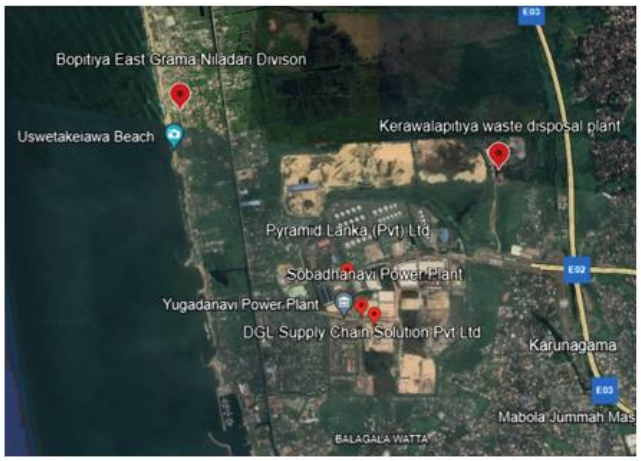

Fig. 1. Arial view of the study area (Ref: Google Earth)

B. Data Collection

In this study, questionnaires, interviews, and field observations were employed to obtain a comprehensive understanding of the ecological and socio-economic impacts of waste disposal and management in the Muthurajawela Wetland. A dialogue with an authoritative representative was engaged to explore various aspects of the historical and current state of waste disposal and management in the neighborhood of the study area. This research employed a questionnaire survey as the primary method of data collection. The target population for this survey included adults residing in areas near the industrial zone in Muthurajawela, Bopitiya East Grama Niladari Division. A random sampling approach was used to select 50 participants. A wide range of population size, including age, gender, income levels, and geographical areas, were included to ensure diversity in responses. Upon accessing the survey, participants were presented with a brief introduction to the research and provided with informed consent information. Data collection occurred in September 2023 while investigating the Muthurajawela industrial zone. The questionnaires targeted information relating

Section 1–Awareness of waste dumping

Section 2–Awareness of environment impacts

Section 3–Perception of health well-being impact and social impacts

Section 4–control measures

Section 5–perceptions on the restoration of Muthurajawela marsh were included.

Ethical clearance was obtained prior to the research due to the participation of human subjects in the study. Their demographic details and responses to the questions were collected only for the purpose of the study, and the respondents were informed about this at the beginning of the survey. All the respondents participated in the survey as volunteers. The respondents' consent was secured for their voluntary participation in the survey after informing the respondents about the purpose of the study and the potential dissemination of the outcome before the survey.

C. Data Analysis

Data obtained from questionnaires was analyzed using statistical techniques while qualitative data collected by way of discussions, interviews, and field observations were analyzed qualitatively.

III. Results

A. Demographic Characteristics

The range of the test population was between 16 to 79 years. The majority of respondents (65%) were 25-54 years old. Nearly 14 % and 21% of the respondents represented the age groups of 15-24 years and 55-79 years, respectively. Within the surveyed group, the majority held diverse occupations, including bank officers, factory storekeepers, drivers, carpenters, hired workers, self-employed individuals, fishermen, and teachers (58%). Meanwhile, 34% comprised housewives and students from higher educational institutions, with the remaining 8%.

B. Opinion of an Authoritative Representative

In this interview, a dialogue with an authoritative representative was engaged. This dialogue proved instrumental in the acquisition of crucial insights about the waste disposal practices at the site. The officer elucidated that the commencement of garbage collection in the vicinity of Kerawalapitiya junction was instigated in 2017, primarily in response to the catastrophic collapse of the Meethotamulla garbage dump. The necessity for an alternative location to accommodate both these degradable and non-degradable waste materials led to the strategic intervention of governmental authorities at that juncture. Degradable materials are those that can be broken down naturally by environmental processes while non-degradable materials are those that do not break down easily in the environment and can persist for a long time. The site is under the management of the Sri Lanka Land Development Corporation (SLDC). In its initial operational phase, the site accommodated a substantial influx of waste, with 250 tons of degradable materials and 350 tons of non-degradable materials being deposited daily, predominantly sourced from the Colombo region. Subsequently, the site has evolved to serve as a central waste collection point, attracting not only municipal contributions but also waste disposal by various government agencies.

A noteworthy transition in the disposal dynamics has transpired, whereby presently, only degradable materials find their way to the site. Furthermore, we were apprised of the meticulous segregation of waste, including the extraction of non-degradable materials such as polythene. In response to our inquiry regarding the utility of the site, the officer disclosed that the disposal process primarily centers on comprehensive composting of the waste materials. Notably, the compost generated is subsequently distributed to the public, with a pricing structure of 18,000 Sri Lankan rupees per ton and 480 rupees for 20 kilograms. Additionally, it was underscored that the administrative authorities have transitioned to a streamlined approach wherein only degradable materials are systematically processed, with a dual focus on environmental and public welfare. The officer's willingness to share these insights proved invaluable to the research, providing a comprehensive understanding of waste disposal practices at the site in question.

C. Results of the Questionnaire Survey

Section 1—Awareness of Waste Disposal

Based on the provided responses, it is evident that 96% of the population was aware of the waste disposal site, while 4% did not know of it. Among those who were aware, 94% had acquired this knowledge through personal observation, 12% through news reports, 8% through community discussions, and 4% expressed uncertainty about their awareness of the matter. When questioned about the significance of Muthurajawela wetland in their lives, the responses revealed that 6% of people or their family members relied on fisheries based in Muthurajawela marsh, 28% mentioned that it attracted tourists and contributed to the income of villagers, while 76% of the population indicated that the wetland held no importance in their lives.

Section 2—Awareness of Environmental Impacts

When questioned about the most significant environmental issues resulting from waste dumping in Muthurajawela wetland, as indicated in Figure 2, the findings were quite revealing. A significant 58% of the surveyed population identified soil pollution as a concern, while an overwhelming 94% pointed to water pollution as the primary issue. Additionally, 24% of respondents acknowledged air pollution, 13% cited harm to wildlife, and 12% expressed concerns regarding the degradation of wetland ecosystems. It's worth noting that no participants attributed these environmental issues to other factors, and 4% were uncertain.

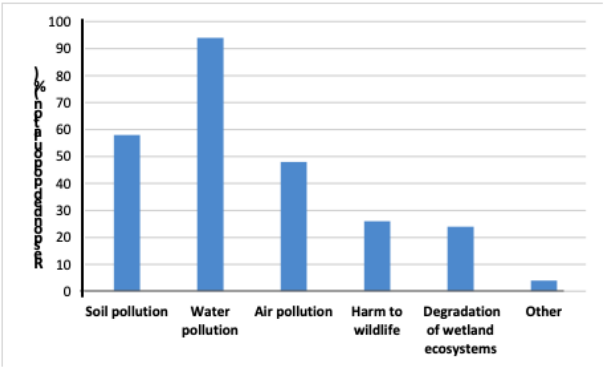

Fig. 2. Significant environmental issues caused by waste disposal in Muthurajawela wetland according to the responded population

Shifting our focus to the primary components of waste, the findings revealed specific statistics: 66% of respondents mentioned food waste, 92% emphasized plastics and polythene, 76% recognized glass materials, 64% acknowledged paper waste, and 28% identified medical waste as notable components. It is important to note that 8% of the population expressed uncertainty regarding waste components. These results are visualized in Fig. 3.

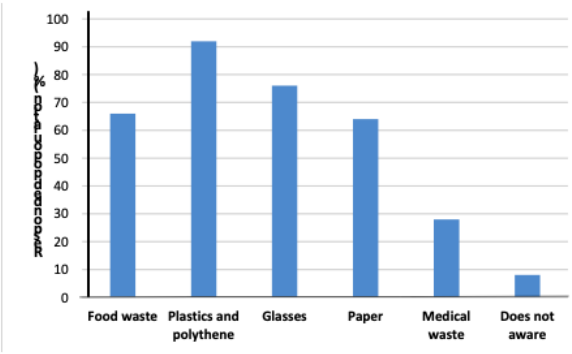

Fig. 3. Main components of waste according to the responded population

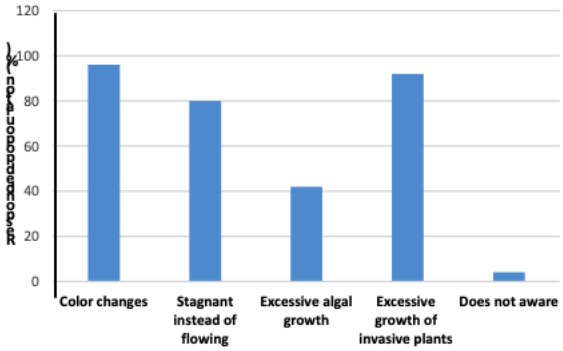

Fig. 4. Observed changes in water quality

Regarding the inquiry about spontaneous combustion, there were no affirmative responses; 100% of respondents denied such occurrences. Additionally, when asked if they had experienced any odors near the waste dumping site, 96% of respondents confirmed the presence of odors.

Based on the questionnaire survey, all members of the population responded that they do not utilize water from Muthurajawela wetland, and there are no reported users of water from that area. Among them, 76% of the respondents stated that the water quality is very poor, while others indicated a lack of awareness regarding water quality. When questioned about the impact of the waste dump on the water quality of the wetland, there were no denials; all respondents acknowledged water pollution. Furthermore, 4% of respondents expressed uncertainty, leaving a substantial 96% with affirmative responses. The questionnaire also probed whether respondents had noticed any changes in the water quality of the Muthurajawela marsh since the commencement of garbage disposal. Shifting our focus to the changes in water quality, a significant 96% of respondents reported alterations in the water's color, while 80% noted the shift from flowing to stagnant water. In addition, 42% observed an excessive growth of algae, 12% noted the overgrowth of invasive plants like common water hyacinth, and 4% were uncertain. These results are visualized in Fig. 4.

According to the questionnaire, a substantial 86% of respondents observed birds and other animals in the marsh feeding on waste. Another question focused on fish mortality in the Muthurajawela marsh due to waste dumping, with 80% of respondents confirming the occurrence of fish mortality. In terms of vegetation death within the marsh, 76% of respondents affirmed the presence of vegetation demise. Additionally, when asked about the presence of animals, including birds and flies, in the marsh, a significant 88% of respondents affirmed their presence. Subsequently, another question explored the respondents' perceptions of a decrease in the number of migratory birds compared to previous years. The results revealed that 34% of respondents noticed a decrease, 10% did not observe a decrease, while others expressed uncertainty and lacked knowledge regarding the matter.

Section 3—Perceptions on Health and Well-Being Impacts

The questionnaire survey dedicated a section to examine the health, well-being, and social consequences of waste dumping in the Muthurajawela wetland. Respondents were queried about their perceptions regarding whether garbage dumping had negative health effects on workers or the local population in the area. An overwhelming 90% of the population, with no dissenting views, while 6% expressed uncertainty, and 4% claimed ignorance, confirmed the existence of such impacts. Respondents also reported an increased prevalence of health issues, including dengue and respiratory problems, attributed to garbage dumping based on their experiences. The questionnaire survey additionally unveiled that 96% of respondents observed alterations in the quality of their well water. The next questionnaire aimed to determine whether individuals had assessed the quality of their well water after waste disposal commenced in the marsh. The results indicated that 64% of the population had conducted tests, while the remaining 36% had not. Next respondents were asked if they had observed stray animals feeding on waste, to which 90% responded affirmatively, while 10% reported not having observed such behavior. Furthermore, question probed whether there had been an increase in stray animals, yielding responses from 94% in the affirmative, and 6% in the negative. In next question, which sought observations regarding an increase in rabies incidents, only 2% of respondents reported affirmatively, with the overwhelming majority, 98%, responding in the negative.

Focused on the observation of an increase in mosquito abundance, all respondents indicated the presence of an increase. Similarity, respondents were asked about the observation of an increase in mosquito-borne diseases like dengue, with 64% acknowledging such observations and 36% negating them. Next participants were queried about an increase in flies within their household due to waste disposal, to which 100% responded in the affirmative. Subsequently, inquired about any perceived increase in food-borne diseases, with 6% responding positively, 88% in the negative, and 6% expressing uncertainty. For next question, which focused on the presence of individuals with skin disorders resulting from contact with the dumping site, 96% answered negatively, while 4% expressed uncertainty. Regarding the administration of medicines for these diseases, received responses wherein no one answered affirmatively, 16% in the negative, 18% expressed

uncertainty, and 66% lacked information. Respondents were asked about the observation of dust emissions on the roads due to waste transportation by tractors, with 96% confirming such observations, none of them negating them, and 4% expressing uncertainty. Subsequently, focused on whether the waste dumping site had a detrimental impact on property values in the area. An overwhelming 80% of respondents affirmed the reduction of property values, while 18% expressed uncertainty, and 2% lacked information. Next respondents were asked if waste transport vehicles had damaged the roads, with 96% confirming such damage, no one denying it, and 4% expressing uncertainty. Next Question inquired whether waste dumping led to flooding during heavy rain, to which 96% answered in the affirmative, no one denied it, and 4% expressed uncertainty. Following this, the inquiry was directed towards whether the disposal of waste had impacted the occupations of the respondents. In response, 58% affirmed an affirmative effect, while 42% indicated a negative impact. Next focus was on the observation of a decrease in tourist attractions following waste disposal, with 84% acknowledging such a decrease, 4% negating it, 4% expressing uncertainty, and 6% lacking knowledge on the matter.

Section 4—Control Measures

This section of the questionnaire survey is focused on the inquiry into control measures. Respondents were queried about their engagement in any actions against the waste dump in their vicinity, with 78% responding affirmatively and 22% indicating otherwise. Similarly, in the next question, which investigated whether the authorities had been informed of the issues faced by resident due to garbage dumping, 78% affirmed that they had indeed apprised the authorities, while 22% reported a lack of communication with the relevant authorities. According to their information, the relevant authorities, including the Grama Niladari, Municipal council, Local council members, and Public Health Inspectors, have taken several actions. These actions included organizing a shramadana campaign and cleaning the village canal, as well as addressing the issue of solid waste in the swamp. Additionally, community participation efforts to reduce solid waste disposal in the Muthurajawela Swamp included shramadana campaigns and protests.

Section 5—Restoration of Muthurajawala Marsh

The prevalent public sentiment revolves around waste disposal being a significant threat to the village. This concern is largely attributed to the substantial garbage-laden lorries causing road damage. Additionally, there are pressing issues related to leachate emissions, soil contamination, and the proliferation of mosquitoes. As per their shared experiences, it is apparent that before the establishment of the industrial zone, the area was pristine and free from unpleasant odors. However, with the advent of factories and the creation of the garbage dump, the quality of water, air, and sound deteriorated. Moreover, the ability to breathe clean air freely was severely compromised.

According to the respondents, there is no involvement in water quality monitoring activities in the Muthurajawela. Inquiries regarding the perspective on the foremost challenges associated with the management and alleviation of pollution in wetlands yielded prevalent viewpoints. These viewpoints underscore the distinctive botanical and aquatic diversity inherent in wetland ecosystems. Consequently, it is posited that the stewardship of these ecosystems should be undertaken in a manner that safeguards their unique biodiversity. Additionally, a notable challenge articulated involves the complexity of wetland management during the rainy season, exacerbated by the substantial influx of waste disposal, which poses a considerable impediment to effective environmental conservation efforts. Next inquired about the awareness of ongoing conservation or restoration efforts in the Muthurajawela wetland, results indicated that none of the respondents were aware of such efforts, with 34% asserting a lack of awareness, 60% expressing uncertainty, and 4% professing a lack of knowledge on the subject. The opinions were taken about improving the water quality and overall health of Muthurajawela wetland. The most common opinion was waste from the industries and smokestacks should not be released into the environment in this area.

IV. Discussion

This study has illuminated several critical aspects of these environmental issues and their potential impact on the region of Muthurajawela. It is critical to emphasize that the responses obtained from the questionnaire survey reveal a significant range of viewpoints and experiences. This variation is attributed to a mixture of causes, including differences in knowledge levels, human interactions, and demographic distinctions. The variety of perspectives revealed by the survey data emphasizes the complexity of the issue under investigation and highlights the need for a thorough and complex strategy to address the ecological and socioeconomic aspects of waste disposal and management in the Muthurajawela wetlands.

This research has illuminated a series of profound ecological impacts. Through the identification of waste dumping sites, quantification of pollutant concentrations, and scrutiny of their ecological repercussions, we have underscored the gravity of the ecological challenges confronting Muthurajawela. The contamination of soil and water, the degradation of habitats, and the potential loss of biodiversity have all been established as tangible outcomes of irresponsible waste management. These findings underscore the fragility of Muthurajawela's ecosystem and the urgent necessity for conservation endeavors and the adoption of responsible waste disposal practices to safeguard its intricate equilibrium. This study constitutes a pivotal call to action in this context. To address the myriad issues that afflict Muthurajawela, it underscores the significance of adopting responsible waste management practices, implementing pollution control measures, and fostering collaborative partnerships involving local communities, businesses, and governmental bodies. Our findings advocate for a holistic strategy that not only acknowledges the biological and socioeconomic interdependencies but also strives to preserve and conserve these invaluable ecosystems, aligning with broader global imperatives concerning wetland preservation and sustainable development. Based on the findings of this

survey, it is imperative for the government to address this issue, as the current level of their contribution is deemed wholly inadequate.

V. CONCLUSION

The research investigation entitled "Assessment of the Ecological and Socioeconomic Impacts of Waste Disposal and Management in Muthurajawela Wetland" has yielded profound insights into the multifaceted challenges confronting this distinctive and delicate ecosystem. The findings from this study underscore the exigency of addressing these challenges to safeguard the ecological integrity of Muthurajawela Wetland and ensure the well-being of the local communities reliant on this natural resource. Of note, our survey revealed that 96% of the surveyed population demonstrated awareness of waste dumping activities in the vicinity of Muthurajawela Wetland. This awareness significantly facilitated the acquisition of pertinent information for our study.

It was observed that a substantial portion of the population had a long-standing association with Muthurajawela Wetland, either from birth or after residing in the area for a minimum of 10 years. Remarkably, none of the respondents relied on water from Muthurajawela Wetland or groundwater for their domestic needs. The majority of respondents rated the overall water quality of Muthurajawela Wetland as "very poor." In response to inquiries about observable changes possibly linked to waste dumping, diverse and concerning accounts were provided. Respondents noted the proliferation of dogs, accompanied by changes in the color and flow of water in the wetland, stagnant water bodies, and the presence of animals like dogs and crows in proximity to the waste dump and the village. These changes were paralleled by increased instances of dengue patients and respiratory problems, particularly among young children, suggesting significant health impacts. The ramifications extended to transportation, with garbage-clogged channels causing flooding, road damage due to heavy garbage-loaded lorries, and frequent flooding during heavy rain, posing transportation challenges for villagers. Furthermore, the study highlighted the increase of mosquito and housefly populations in the area, with reports of dengue cases and unpleasant odors emanating from the garbage dump. Despite complaints submitted to local councils and government agencies, there was a notable absence of effective action. The results underscore the urgency of sustainable waste management practices, pollution control measures, and collaborative endeavors involving government entities, businesses, and local communities to address the myriad challenges faced by Muthurajawela. The rehabilitation of waste disposal site is essential, necessitating the complete removal and restoration of the marsh. In light of the research survey results, it is paramount for the government to significantly enhance its current level of contribution to address this issue, as the existing efforts are considered wholly inadequate.

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2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

Capsaicinoid Content of *Capsicum* spp. Cultivated Under High Temperature Stress

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***Abstract*—Capsaicinoid content of chili peppers plays an important role in the food industry. Environmental temperature is increasing continuously because of the greenhouse effect. High temperature is a stress for plants. Compounds like capsaicinoids and the number of seeds in fruits will change as a response to such stresses. The present experiment was conducted to determine the effect of temperature stress on capsaicinoids and the number of seeds in the 'Takanotsume', 'Habanero' and 'Himo' chili varieties. Temperature stress conditions were provided in a greenhouse and control environmental conditions were provided to the plants in an open field at the Faculty of Agriculture, Shinshu University. After harvesting fruits at 20 and 30 days after flowering (DAF), the number of seeds was counted and the capsaicinoid contents were measured using high-performance liquid chromatography. The number of seeds decreased with the temperature stress. Capsaicinoid content was significantly higher in the temperature stress condition than the control condition in all varieties except 'Himo' at 20 DAF. Altogether, an inverse relationship was observed between capsaicinoid content and the number of seeds.**

Keywords— Capsaicinoid, chili pepper, temperature stress

I. INTRODUCTION

Chili peppers are important in the food and pharmaceutical industries and are widely cultivated spices around the world. Chili pepper belongs to the genus *Capsicum* in the family Solanaceae. Capsaicinoids are the active ingredients that give chili peppers their hotness or burning taste. The interaction between the cultivar (genetic traits) and the growing environment significantly affects the accumulation of capsaicinoids in chili peppers. Drought, salinity stress, light, and fertilizer conditions are the environmental factors that affect chili pepper pungency and fruit quality. At present, the global temperature is continuously increasing and it is expected to increase by 0.5–2.8 ^{0}C at the end of the 21st century [1]. Plants also can be affected in many ways by this temperature increase, which is a stressor for plant growth and development.

There are a limited number of experiments on the effect of temperature stress on chili peppers because it is difficult to provide temperature stress without causing drought stress and changes in light conditions. On the other hand, most of the studies were mainly focused only on growth and yield parameters. The relationships of environmental stresses such as drought stress [2], salinity stress [3], and excess P fertilizer stress, with capsaicinoid and average numbers of seeds, have been already tested, except for temperature stress. Therefore, the present experiment was conducted to investigate the effect of temperature stress on capsaicinoids and seed content in chili pepper.

II. METHODOLOGY

A. Location and the Media Used in the Experiment

The experiment was carried out at Alpine Field Research and Education Centre, Faculty of Agriculture, Shinshu University, Minamiminowa, Nagano, Japan. 'Takanotsume' and 'Himo' (*C. annuum*) and 'Habanero' (*C. chinense*) varieties were used for this experiment.

The experiment was conducted from June to September, 2022. 15 cm long seedlings were transplanted into plastic pots (18 cm in diameter, 2.2 L) filled with a commercial potting medium. The first set of flower buds was removed after applying the treatments. BB fertilizer 552 (N: P: K, 15:15:12) was added following the standard recommendation.

B. Testing the Effect of Temperature

Two temperature conditions were provided during the present Experiment: a temperature stress was tested inside a greenhouse and a control experiment was conducted outside the greenhouse. The maximum average temperature was 44.4 ^{0}C, and the minimum average temperature was 14.9 ^{0}C inside the greenhouse. Outside the greenhouse, the maximum average temperature was 36.7 ^{0}C and the minimum average temperature was 13.5 ^{0}C. Similar light conditions were provided with 50% shade for both greenhouse and control tests. Excess water was provided to prevent the effect of drought. Overflow from the pot was retained in a plate under the pot and allowed to be absorbed through the pot base. Five plants were used for each experiment. One fruit from each plant was harvested at 20 and 30 DAF and stored in a -80 ˚C refrigerator until used for capsaicinoid analyses.

C. Analysis of the Capsaicinoid Content and Seed Counting

The number of seeds was counted before capsaicinoid analysis. The capsaicinoid content of the placenta septum was measured using high-performance liquid chromatography. Data were analyzed by using an Analysis of Variance (ANOVA) in Minitab 17.

III. Results and Discussion

When the number of seeds of all three varieties harvested at both 20 and 30 DAF was compared, a significantly lower average number of seeds was present in the temperature stressed condition than in the control condition. Both 'Takanotsume', and 'Habanero' showed higher capsaicinoid content during the temperature stress compared to the control at both 20 DAF and 30 DAF. Surprisingly, 'Himo' did not show a significant difference in capsaicinoid content between the temperature stress and the control at 20 DAF (Tab. 1).

However, significantly higher capsaicinoid content was reported in the temperature stress than the control condition at 30 DAF. When the capsaicinoid contents that were reported during the same treatment and the same variety were compared based on harvesting times, no significant difference was shown in 'Takanotsume' and 'Habanero'. However, in 'Himo', fruits harvested at 30 DAF showed higher capsaicinoid content in the temperature stress condition than fruits harvested at 20 DAF in the temperature stress treatment. Among all the treatments, the highest capsaicinoid content was reported in 'Habanero' during the temperature stress condition harvested at 30 DAF, whereas the lowest was reported in 'Himo' which was grown under control conditions, harvested at 20 DAF.

The pungency or the hotness which is considered as the main characteristic of the chili fruits, increases when the amount of capsaicinoid is increased. An inverse relationship can be observed between the average number of seeds and the capsaicinoid content in all varieties at all harvesting stages. Under the temperature stress condition, capsaicinoid content was increased when the average number of seeds was decreased.

During the seed formation period of chili peppers, exposure to high temperatures after anthesis, severely affects the fruit growth and decreases the number of seeds per fruit in 'Shishito' peppers [4]. The biochemical pathways of the production of lignin and capsaicin are linked where the production of one compound adversely affects the production of the other compound, resulting in a trade-off between the two compounds [5]. Lignin is a major structural compound that is associated with the seed coat. The need to produce lignin with the reduction of seed number becomes less, providing space to produce high capsaicinoids in a trade-off scenario. This phenomenon could be possible and is the most suitable explanation for the higher amount of capsaicinoid content reported during the temperature stress condition in the present study. However, the 'Himo' variety was an exception with regard to the capsaicinoid content reported during the stress conditions. In the case of 'Himo' pepper, HPLC could not detect a sufficient amount of capsaicinoid at 20 DAF to support the results of other varieties.

IV. Conclusion

Since the capsaicinoid content increases, the pungency was enhanced when temperature stress was applied. As a suggestion, if farmers use temperature stress conditions by growing in a greenhouse, rather than growing plants at the normal environmental temperature, they can get more pungent chili fruits.

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TABLE 1. CAPSAICINOID CONTENT AND AVERAGE NUMBER OF SEEDS OF 'TAKANOTSUME', 'HABANERO' AND 'HIMO' GROWN UNDER DIFFERENT TEMPERATURE TREATMENTS IN 2022

Varieties	Temperature tretment	Capsaicinoid content of placenta septum (µg·g-1 DW)		Average number of seeds	
		Harvesting date		Harvesting date	
		20 DAF	30 DAF	20 DAF	30 DAF
Takanotsume	High T-Stress	45242 ± 5710 a	49170 ± 9474 x	28.8 ± 4.2 d	30.6 ± 1.9 q
	Control	29623 ± 3699 b	34063 ± 4085 y	37.0 ± 3.4 c	38.0 ± 2.7 p
Habanero	High T-Stress	102850 ± 2419 a	126980 ± 17304 x	18.8 ± 2.6 d	23.2 ± 1.7 q
	Control	78545 ± 3065 b	93358 ± 9271 y	26.4 ± 2.2 c	30.6 ± 2.2 p
Himo	High T-Stress	795 ± 91 a	2469 ± 241 x	28.0 ± 4.5 d	28.2 ± 2.4 q
	Control	597 ± 85 a	597 ± 350 y	36.6 ± 3.6 c	37.0 ± 2.8 p

Values (means ± standard deviation, n=5) followed by the different letters (a, b, x, y, d, c, p and q) in a column of each temperature treatment are significantly different at 5% level by Tukey's pairwise test.

2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

Improvement of Quality of Biocatalytic Fertilizer Through Incorporation of Biomass-Based Nutrients

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***Abstract*—Biochar, harnessed as a biocatalyst, offers a transformative opportunity to revolutionize the production of biochar fertilizer, achieving both higher quality and cost-effectiveness. This study aimed to develop an exceptional organic fertilizer by harnessing the catalytic potential of rice husk biochar. The biochar was activated by formulating aqueous biocatalysts in separate aerobic reactors. Five aerobic reactors were constructed using 10 L plastic containers and 3 mm diameter transparent flexible tubes. The process involved blending a mixture of shredded organic (*Gliricidia sepium* leaves, *Tithonia diversifolia* leaves, and *Micropiper pellucidum*, with five different ratios) with a precisely measured amount of water. 10 g of Eppawala rock phosphate (ERP) was added to each solution. These prepared slurries were then transferred into the custom-made reactors, and continuous aeration was maintained throughout the experimental period. Size-reduced biochar was added intermittently to each reactor. Treatment 4 ((*Gliricidia* (500g) + *Thithoniya* (500g) + *Micropiper pellucidum* (500g) + Biochar (453g) + ERP (10g)) consistently displayed higher nutrient levels on day 01 and day 7 (N = 1540 mg/Kg, P =72 mg/Kg, K = 3028 mg/Kg), and also consistently exhibited high pH (7.36±0.21) levels throughout the study. Due to its ability to retain and gradually release nutrients, treatment 4 presents itself as a compelling subject for further exploration and utilization. The composition of treatment 4 is well-suited for the creation of organic fertilizers enriched with biochar biocatalysts, compost, ERP, and other components, resulting in a nutrient-rich end product.**

Keywords—Biochar, biochar-biocatalyst, gliricidia green leaves, macropiper pellucidum, tithonia diversifolia

I. INTRODUCTION

Intensive agricultural activities have long been recognized as a driving force behind the depletion of soil carbon storage, effectively diminishing their capacity to function as vital carbon sinks[1]. To address this pressing concern, numerous strategies have been explored to bolster soil carbon sequestration, including conservation practices, the incorporation of biosolids and organic waste into soil amendments, and an emphasis on diversified crop rotations [2]. Organic residues, when applied to agricultural soils, hold the promise of not only enhancing soil carbon storage but also mitigating greenhouse gas emissions[3]. However, a persistent challenge associated with the utilization of organic waste materials, such as green manures and composts, lies in their relatively swift decomposition rate, rendering them a source of carbon emissions rather than an effective carbon sink [4]. In stark contrast, organic waste possesses the potential to transform into biochar, a substance characterized by its notably slow decomposition rate. Biochar has emerged as a stable and enduring alternative to compost, making it a promising tool for improving soil carbon sequestration [5]. Various physical and chemical attributes of biochar, including surface area, degree of condensation, and particle size, play pivotal roles in determining its stability within soils [6].

This paper delves into the compelling rationale for the co-application of biochar and compost as organic soil amendments. Composting, a widely employed organic soil supplement, is celebrated for its contributions to enhancing soil quality and sequestering carbon post-application [7]. Yet, the aerobic microbial degradation inherent to composting processes carries an unfortunate side effect: the avoidable loss of essential nutrients, particularly nitrogen. Studies reveal that the total nitrogen loss during composting can span an alarming range, from 16% to 76% [8]. This substantial nitrogen loss not only diminishes the nutritional value of the final compost products but also raises concerns about its environmental impact. Recognizing the shared objective of enhancing soil quality and nutrient retention, this paper underscores the potential synergy between biochar and compost when utilized together [9]. Research by Hardy Schulz (2014) demonstrated that co-composted biochar significantly promoted plant growth, particularly in sandy soils, making it an attractive prospect for augmenting soil fertility. Additionally, biochar, known for its nutrient-absorbing properties, can be employed during composting to curtail nutrient losses, particularly nitrogen, thus yielding nutrient-dense green manure[10]. However, further enhancements can be achieved by introducing biochar to a biocatalyst [6, 11], a material facilitating biochemical

reactions in living organisms. Such biocatalysts can occur either chemically or biologically, with the latter offering unique agricultural advantages. By catalyzing biochar with natural enzymes that exhibit microbial activity, it is possible to forge a path towards entirely organic fertilizers enriched with nutrients derived from biocatalysts, compost, and Eppawala Rock Phosphate (ERP). This study aimed to develop bio-catalyzed organic fertilizer utilizing biochar, laden with essential elements for both short-term and perennial crops.

II. Methodology

A. Addition of Ingredients and Pre-processing

Collection of Raw Materials and Preprocessing

2 kg of *Tithonia diversifolia* leaves, 2 kg of *Gliricidia sepium* leaves 3 kg, 1.5 kg of *Micropiper pellucidum* [12, 13], 2 kg of Rice husk biochar, and 50 g of Eppawala Rock Phosphate (ERP) were collected. The collected *Tithonia diversifolia*, Glydrisyria sepium leaves, and *Micropiper pellucidum* were cut into small particles separately using a separate grinder and each mixture was taken to prepare a fertilizer solution. The added ingredients can be analyzed to determine the initial composition. Rice husk biochar was obtained from a fertilizer producing company and *Thithoniya diversifolia*, *Gliricidia sepium* leaves, and *Micropiper pellucidum* were collected from the Sri Lanka Technological Campus Padukka premises. The biochar was produced under pyrolytic conditions, using a temperature range of 450 °C for a period of 2.5 hours. Particle size of selected biochar was reduced and particles <4 mm was used for the experiment [6]. Preprocessed *Thithonia diversifolia* leaves and size-reduced (<2 mm) *Gliricidia sepium* green leaves were analyzed separately for moisture content (MC), ash content, total solids (TS), and volatile solids (VS) concentration using APHA Method 2540-G. Statistical analysis was carried out employing Analysis of Variance (ANOVA).

Reactor Fabrication, Biocatalysts Preparation, and Analysis

Five aerobic reactors were constructed using 10 L plastic containers and 3 mm diameter transparent flexible tubes. The plastic containers remained unaltered, and their lids were intentionally left open to facilitate gas exchange and promote aeration, specifically to accommodate the insertion of an aerator tube. Continuous aeration was maintained using an aerator pump (SDA-2800). The process involved blending a mixture of shredded organic with a precisely measured amount of water to create a homogenous solution. Similarly, the chopping and blending procedure was applied to prepare separate solutions from 2 kg of *Gliricidia sepium* leaves, 2 kg of *Tithonia diversifolia* leaves, and 1.5 kg of *Micropiper pellucidum* leaves. In each case, 100 mL of the resulting solution was set aside for characterization. The remaining slurries were diluted with water to achieve a consistent organic matter-to-water ratio of 1:4. During this dilution process, 10 g of ERP was added to each solution as P source. *Micropiper pellucidum* leaves were incorporated as a rich source of K. For these five treatments were applied as given in Tab. 1.

TABLE 1: TREATMENTS USED FOR THE EXPERIMENT

Treatment	Composition of the biochar biocatalyst mixture
Treatment 1	*Gliricidia* (1Kg) + Biochar (302 g) + ERP (10g) + Water (4L)
Treatment 2	*Thithoniya*(1Kg) + Biochar (302g) + ERP(10g) + Water (4L)
Treatment 3	*Gliricidia* (500g) + Biochar (402g) + *Micropiper pellucidum* (500g) + ERP (10g) + Water (4L)
Treatment 4	*Gliricidia* (500g) + *Thithoniya* (500g) + *Micropiper pellucidum* (500g) + Biochar (453g) + ERP (10g) + Water (4L)
Treatment 5	*Thithoniya* (500g) + *Micropiper pellucidum* (500g) + Biochar (302g) + ERP (10g) + Water (4L)

These prepared slurries were then transferred into the custom-made reactors, and continuous aeration was maintained throughout the experimental period. To adjust the pH of the reactors to a neutral value of 7, size-reduced biochar was added intermittently to each reactor. The quantity of added biochar was carefully measured and recorded as outlined in Tab. 2.

TABLE 2: QUANTITIES OF BIOCHAR ADDED TO EACH BIOCATALYTIC REACTOR

Treatment	Quantity of biochar added (g)
01	Day 01 – 302g
02	Day 01 – 302g
03	Day 01 – 302g, Day 03 – 100g
04	Day 01 – 453g
05	Day 01 – 302g

Representative samples were collected from each reactor and analyzed daily for 07 days. This analysis included pH measurements using a pH meter (Thermo Scientific, model Orion 2 star), as well as assessments of EC, salinity, and TDS (Total Dissolved Solids) concentration obtained using a conductivity meter (Thermo Orient Model 145 A). Additionally, TS (Total Solids) and TSS (Total suspended solids) were determined following the APHA Method 2540-G. Furthermore, total nitrogen (N) content was determined using the Kjeldahl method, total potassium (K) was analyzed through the Exchangeable Base method with a flame photometer, and total phosphorus (P) was measured using the Olsen P method.

III. Results and Discussion

In the study of biocatalytic fertilizers enriched with biomass-based nutrients, various treatments were explored, each constituted by a unique combination of *Gliricidia sepium*, *Tithonia diversifolia* (wild sunflower), *Micropiper pellucidum*, biochar, and ERP as raw materials. The research aimed to comprehend the implications of these treatments on nutrient dynamics, soil health, and their potential applications in sustainable agriculture. A pivotal aspect of these biocatalytic fertilizers was their pH levels, which played a significant role in nutrient availability. The pH ranged from mildly alkaline (pH 7) to moderately alkaline (pH 10) [6]. Interestingly, the pH varied across treatments, showcasing the influence of raw materials on the biocatalytic mixture's pH. Notably, Treatment 4, which contained all the mentioned components, consistently exhibited higher pH levels throughout the study, highlighting its potential alkaline effect.

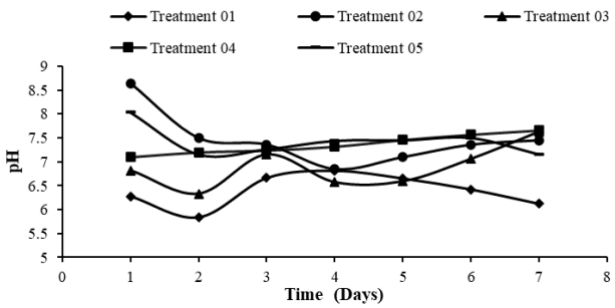

Fig. 1. pH variations with time

This was crucial as a higher pH (5.5 to 7) could enhance nutrient availability in the soil, making essential elements more accessible for plant uptake. Furthermore, the study delved into TDS and EC as vital parameters for assessing nutrient concentration and soil salinity. Treatments 4 and 5 consistently showed higher TDS and EC levels, indicating a potentially increased nutrient solubility, but the need for managing potential soil salinity concerns. Moreover, TSS measurements reflected the nutrient retention capabilities of the treatments, with Treatment 1 consistently demonstrating an upward trend, suggesting effective nutrient retention, especially in the presence of ERP. On the other hand, Treatment 3 displayed fluctuations, potentially due to the influence of *Micropiper pellucidum*, warranting further analysis. TS measurement emphasized the complex nature of these mixtures, with Treatment 4 showing substantial variations in TS values, suggesting intricate compositional dynamics.

TABLE 3: CHARACTERISTICS OF THE TREATMENT MIXTURES DURING THE STUDY PERIOD

Treatment	pH	TDS (mg/L)	EC (mS/cm)	TSS (mg/L)	TS (mg/L)
Treatment 01	6.40 ±0.34	3925.14 ±1313.195	6439.43 ±1823.63	55571.43 ±26893.97	72142.86 ±105550
Treatment 02	7.47 ±0.57	2969.57 ±503.54	5939.14 ±1007.08	77285.71 ±43942.06	429285.7 ±355568
Treatment 03	6.88 ±0.44	3106.86 ±139.29	6215.43 ±276.08	32714.29 ±105550	175571.4 ±47240.02
Treatment 04	7.36 ±0.21	3108.86 ±179.13	5962.43 + - 682.54	41857.14 ±12088.96	161285.7 ±57438.99
Treatment 05	7.43 ±0.31	2598.71 + - 331.70	5196.29 ±662.40	22428.57 ±2699.206	25587.1 ±164975.2

In conclusion, the variations in nutrient content, including Total Nitrogen (N), Total Phosphorus (P), and Total Potassium (K), showcased the potential of these biocatalytic fertilizers for sustainable agriculture.

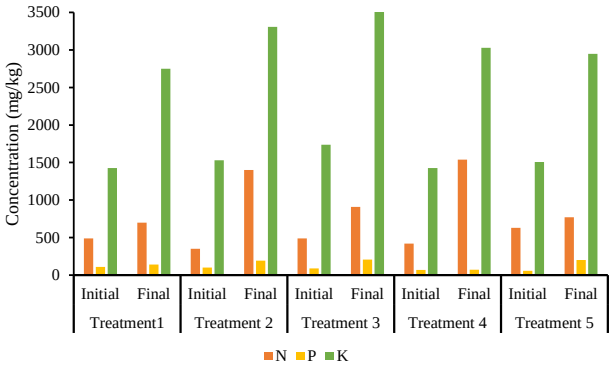

Fig. 2. Total N, P, K contents variation of catalysts

Treatment 3 exhibited a significant increase in nitrogen content from an initial level of 490 mg/kg to a final level of 910 mg/kg. Similarly, phosphorus levels increased notably from 88 mg/kg to 208 mg/kg, and potassium levels rose from 1,737 mg/kg to 3,625 mg/kg. In contrast, treatment 4 displayed a lower initial nitrogen content of 420 mg/kg, which increased substantially to 1,540 mg/kg. However, phosphorus levels saw a minimal change, starting at 68 mg/kg and reaching 72 mg/kg. Potassium levels showed an increase from 1,426 mg/kg to 3,028 mg/kg. Treatment 4 consistently displayed higher nutrient levels on day 01 and day 07 (N= 1540 mg/Kg, P=72 mg/Kg, K=3028 mg/Kg) reflecting its superior nutrient retention and release capabilities, making it a promising candidate for further investigation and application. The composition of treatment 4 is suitable for developing organic fertilizer with biochar biocatalyst, compost, and ERP, etc. which will be rich in nutrients. Continuous monitoring and customization of nutrient management strategies are recommended to maximize their effectiveness in developing fertilizers to achieve sustainable agriculture goals.

IV. CONCLUSION

The study of biocatalytic mixtures enriched with biomass-based nutrients has unveiled the intricate interplay between raw materials, pH, nutrient dynamics, and their implications for sustainable agriculture. The research encompassed five distinct treatments, each comprising a unique combination of *Gliricidia sepium*, *Tithonia diversifolia* (wild sunflower), *Micropiper pellucidum*, biochar, and ERP as the raw materials. The findings have several key implications. First, the pH variations in the biocatalytic mixtures have highlighted the importance of raw materials in modulating soil pH. Treatment 4 consistently exhibited higher pH levels, indicating its potential to impart alkalinity to soils. This effect can significantly influence nutrient solubility and availability, especially for crops favoring alkaline conditions, thus holding promise for tailored nutrient management. The analysis of TDS and EC emphasized the need for balanced nutrient solubility and the management of potential soil salinity concerns. Treatments 4 and 5 consistently showed elevated TDS and EC levels, suggesting an increased nutrient solubility, while Treatment 2 consistently displayed lower TDS and EC values. The careful selection of treatments is crucial to cater to crop and soil requirements and to minimize adverse effects on soil salinity. Treatment

4, composed of *Gliricidia*, *Thithonia diversifolia*, *Micropiper pellucidum*, biochar, and ERP, consistently exhibited higher nutrient levels and retention across various parameters, suggesting its efficacy in nutrient management. This outcome offers significant promise for advancing environmentally friendly and high-yield agriculture, emphasizing the need for further research to understand the mechanisms underlying its superior performance.

IV. ACKNOWLEDGMENT

This investigation received financial support from the Responsive Research Seed Grant (RRSG) 3rd cycle of the Sri Lanka Technological Campus. Grant No-RRSG.22.0811.2

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2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

Investigation of Low-Cost Amino Acid Production Methods from Abundant Nitrogen-Rich Green Materials in Sri Lanka

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***Abstract*—Amino acid fertilizer is a type of organic fertilizer that is made up of the building blocks of proteins. It is a highly effective fertilizer that can be used to improve soil fertility, plant growth, and crop yield. Amino acid fertilizer is also important for organic farming, as it helps to improve the soil's ability to retain nutrients and water. Therefore, this study was conducted to produce amino acid fertilizer using microbial fermentation to secrete amino acids from abundant nitrogen-rich green materials. The method involved selecting a cost-effective amino acid production approach that utilized anaerobic microorganisms from the soil. Two nitrogen-rich plant species, *Tithonia diversifolia*, and *Gliricidia sepium*, were identified for amino acid production. The process included maceration to break down plant materials, followed by hydrolysis to convert proteins into amino acids. Finally, the mixture was fermented in anaerobic conditions. The study found that the Gliricidia mixture had a higher total N content (700 mg/kg) and amino acid concentration (4.375 g/kg) than the Tithonia mixture (420 mg/kg and 2.625 g/kg, at the end of the experiment (on day 7) respectively). These results suggest that *Gliricidia sepium* is a promising green material for the production of amino acid fertilizers using microbial fermentation. This research has the potential to help Sri Lanka's farmers produce their amino acid fertilizer at a low cost, which could improve crop yields and food security.**

Keywords—Organic fertilizer, amino acid, microbial fermentation

I. INTRODUCTION

Proteins are made up of substances called amino acids. Proteins and amino acids are basic components of life. Amino acids are the byproducts of the digestion or breakdown of proteins. A basic amino group (NH_2), an acidic carboxyl group (COOH), and an organic R group (side chain) that is specific to each amino acid make up an amino acid which is an organic molecule [1]. Amino acids are also organic fertilizers and they are usually manufactured by the raw materials of the animal residual body, plant straw, caster bean cake, and vinasse as well [2]. These fertilizers are stress-reducing agents and good nitrogen resources as well. Mostly, they are used in crop production for better results. It contributes to the faster, more efficient absorption of nutrients by the plant. The key benefit of utilizing this is that plants may quickly assimilate the amino acid without the need for any chemical or microbial digestion. Plants immediately utilize amino acids through plant tissues, and the excess breaks down into water-soluble nitrogen is absorbed by the plant roots [3]. Moreover, there is a good possibility to use the waste of amino acid production as a raw material for biogas and biochar production.

Within the last two decades, biotechnical engineering methods for amino acid production have shown major improvements in the agriculture sector. According to the latest statistics, half of the world's population is covered by synthetic nitrogen fertilizers [4]. Normally, organic fertilizer of amino acids is made from animal and plant waste. These contain rich amounts of protein, phosphorus, and potassium. Amino acid fertilizers are the most recent plant nutrition innovations in agricultural production systems. [5]. Amino acid fertilizers are becoming increasingly popular due to their ability to improve crop yields and quality. The global amino acid fertilizer market is expected to grow significantly in the coming years, driven by increasing demand for high-quality food and the need for sustainable agriculture practices. The production of amino acid fertilizers is distributed across various regions of the world, with Asia-Pacific dominating the market. China and India are the major producers in the region [6]. Europe and North America are also significant markets for amino acid fertilizers, with the growing trend towards organic farming and sustainable agriculture practices [7]. Hence, it will provide basic nutrients for crops and update the soil's organic matter. Hence, it is crucial to concentrate on these components and techniques to produce fertilizers using amino acids. Therefore, this study evaluated the potential of using the green materials *Gliricidia sepium* and *Tithonia diversifolia* to produce amino acid fertilizers using microbial fermentation

II. MATERIALS AND METHOD

A. Selection of Amino Acid Production Method and Microorganisms

The methodology commenced with a comprehensive literature review to identify a cost-effective amino acid production method that leveraged nitrogen-rich green materials and biomass-derived intermediates. The chosen method involved laboratory-scale microbial fermentation, utilizing anaerobic microorganisms obtained from soil.

B. Microorganisms Containing Media Selection

The research assumed the presence of fermentative bacteria, specifically *Corynebacterium glutamicum* and *Bacillus spp.* These facultative anaerobic gram-positive bacteria were expected to be present in soil, sewage, vegetables, and fruits [8]. Soil samples were collected from

agricultural farmland for the extraction of these microorganisms with the use of a hand glove, spatula, and sterile polythene bag. A spatula was used to remove the overlying earth and collect samples from about 3 cm depth [9]. The microbial culture was separated by diluting the soil sample in sterile normal saline and heated at 80 ^{o}C for 10 minutes.

C. Identification of Abundant Nitrogen-Rich Green Materials

After researching nitrogen-rich plant species in Sri Lanka, two primary candidates, *Tithonia diversifolia* (Mexican sunflower) and *Gliricidia sepium*, were identified as nitrogen and potassium-rich green materials suitable for amino acid production. Both plants have high nitrogen contents, typically around 4.2% and 4.7%, on a wet basis respectively [10]. This makes them valuable sources of nitrogen for crops, which is an essential nutrient for plant growth.

D. Maceration and Hydrolysis for Amino Acid Production

i). Maceration Process

The methodology initiated with the maceration process is aimed at breaking down raw materials, primarily plant-based sources rich in proteins, into smaller particles. This physical breakdown increased the surface area, enabling subsequent processes, especially hydrolysis, to access valuable components within the raw materials. The raw materials, *Gliricidia sepium* and *Tithonia diversifolia* (Mexican sunflower leaves) were mechanically crushed using a grinder.

ii). Hydrolysis

After maceration, hydrolysis was the critical step wherein proteins present in the raw materials were broken down into individual amino acids. The addition of water in a 1:2 ratio to the macerated raw materials mixture created an environment conducive to enzyme activity. Hydrolysis experiments were conducted over a 24-hour duration.

iii). Fermentation

The methodology progressed to the fermentation stage, wherein the mixture obtained from the maceration and hydrolysis process was combined with the extracted microorganism culture to initiate the fermentation process. Sealed containers were used to create an anaerobic environment for the fermentation process. Monitoring was essential to determine the endpoint, dependent on the specific microorganisms used and the desired outcome. Samples were collected every 24 hours to facilitate qualitative and quantitative estimations of amino acid production for 7 days. To analyze total nitrogen samples were collected on the 1st, 3rd 5th, and 7th day of the experiment period. Available potassium (K) (wet digestion (HNO_3: $HClO_4$ (9:4)); estimated using atomic absorption spectroscopy), available phosphorous (P) (wet digestion (HNO_3: $HClO_4$ (9:4)); vanadium phosphomolybdate method; estimated using UV-visible spectrophotometer) were analyzed on the last day of the experiment (7th day).

iv). Laboratory Scale Experiments

The methodology involved the utilization of the Kjeldahl method for testing total nitrogen concentration. This technique involved digesting prepared fertilizer samples with a catalyst and sulfuric acid, followed by distillation and titration with sodium hydroxide. For amino acid concentration analysis, the N:P factor (6.25) was employed [11]. This factor, which estimates protein content based on nitrogen analysis, was instrumental in calculating the amino acid concentration. Daily analysis included parameters such as pH (using pH meter Thermo Scientific, model Orion 2 star), electrical conductivity (EC), total dissolved solids (TDS) (EC and TDS meter, Thermo Orient Model 145 A), total solids (TS) (using oven-dried method (using APHA Method 2540-G), and total suspended solids (TSS) using the gravimetric method (using APHA Method 2540-G).

III. Results and Discussion

Two types of treatments were produced under an anaerobic environment using *Gliricidia sepium* and *Tithonia diversifolia* as the raw materials. Only matured leaves were taken for the experiment. When grinding the leaves, it was observed that *Tithonia diversifolia* has a higher moisture content than *Gliricidia sepium*, while *Gliricidia sepium* has a higher fiber content. The soil sample was taken as the medium containing fermentative microorganisms, assuming that this medium contained fermentative bacteria. The soil sample was collected from uncultivated agricultural farmland at the university premises. It was observed that the agricultural farmland had been subjected to a period of heavy rainfall, which resulted in elevated soil moisture levels. The composition of suitable microorganisms in soil samples may change under these conditions.

In this experiment, two mixtures, Gliricidia and Tithonia, were studied over 07 days to assess changes in various parameters. The Gliricidia mixture initially experienced a decrease in pH due to acidogenic reactions. In contrast, the Tithonia mixture maintained a more favorable pH range for agricultural applications throughout the experiment. Both mixtures exhibited increasing electrical conductivity, TDS, and TSS, suggesting the accumulation of ions, metabolites, and microbial biomass as shown in Table 1. The EC of the Tithonia mixture was slightly higher than that of the Gliricidia mixture throughout the experiment. Both mixtures showed a gradual increase in EC values, likely due to the accumulation of ions as a by-product of the fermentation process. On day seven, both mixtures had an EC value of 7,596 mS/cm, indicating a significant increase from their initial values. Similar to EC, the TDS values of both mixtures exhibited fluctuations over the experimental period. On day seven, both samples had TDS values of 3,798 ppm, showing an increase from their initial values. The accumulation of metabolites and waste products from the fermentation process contributed to the increase in TDS.

The TSS content in both mixtures increased significantly by the end of the experiment. The initial and final TSS values of the Gliricidia mixture were 8,000 mg/l and 54,000 mg/l, respectively, while the TSS values of the Tithonia sample changed from 7,000 mg/l initially to 44,000 mg/l at the end. TSS represents solid particles suspended in the liquid phase of the fermentation broth, including microbial cells and undigested organic matter. The increase in TSS is associated with the growth and proliferation of microorganisms during fermentation. The TS content also exhibited continuous fluctuations in both mixtures throughout the experiment, with the Tithonia mixture having slightly higher values. On day seven, the TS values of both mixtures were close, indicating an accumulation of both dissolved and suspended solids,

including microbial biomass, cell debris, and undigested organic matter.

TABLE 1. CHARACTERISTICSOF TREATMENT MIXTURES DURING THE EXPERIMENTAL PERIOD

Sample	pH	EC (ms/cm)	TDS (ppm)	TS (mg/l)	TSS (mg/l)
Tithonia d.	6.99 ±0.16	6851.14 ±898.12	3409.43 ±449.02	20400 ±6485.88	19000 ±12206.56
Gliricidia s.	4.7 ±0.37	6759.71 ±741.22	3380 ±370.53	27057.14 ±4878.13	22000 ±15307.95

The nutrient contents of the two mixtures were dependent on the microbial activity throughout the experimental period. When comparing the initial nutrient contents of both mixtures, the total N content of the Tithonia mixture (210 mg/kg) was higher than the Gliricidia mixture (140 mg/kg) and after that, the total N content of the Gliricidia mixture was increased gradually and had a very high level of nitrogen content (700 mg/l) compared to the Tithonia mixture (420 mg/kg) at the end of the experiment. On the other hand, the Tithonia mixture had a high value of available K (1,641.4 mg/kg) compared to the available K (1,521.9 mg/kg) of the Gliricidia mixture. The Gliricidia mixture had a high value of available P (56 mg/kg) compared to the available P (44 mg/kg) of the Tithonia mixture.

In the Gliricidia mixture, the total N content was 700 mg/kg and the amino acid concentration was 4.375 g/kg on the 7th day which was the maximum reported value. In the Tithonia mixture, the total N content was 420 mg/kg and the amino acid concentration was 2.625 g/kg on the 6th day and the 7th day which were the maximum reported values. It can be due to high microbial population and activities towards the middle of the experiment and then decreasing microbial activities with gradual death of microbes due to lack of substrate. The rapid increase in total N level and the amino acid concentration on the 7th day could be attributed to the increase in the growth of microorganisms along with the gradual increase in pH to a favorable value. Within seven days, total N content and the amino acid concentration of the Gliricidia mixture had a distinguishable increase compared to the Tithonia mixture.

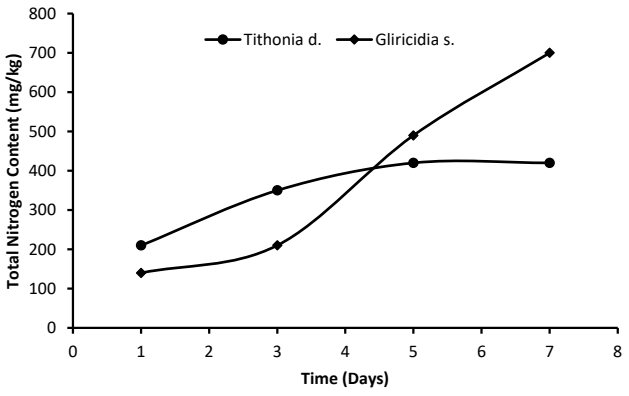

Fig. .1 Variations of total nitrogen concentration of samples with time

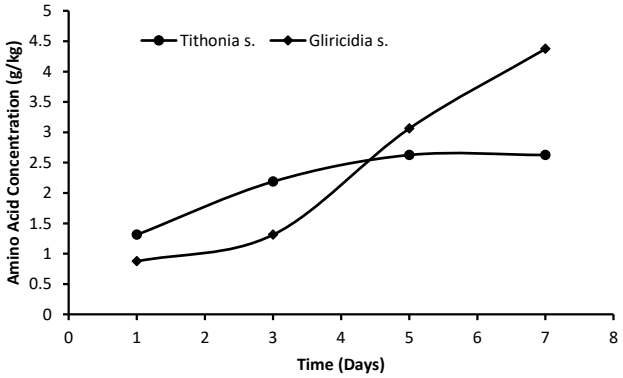

Fig. 2. Variations of amino acid concentration of samples with time

To further enhance this research and maximize amino acids and nitrogen concentration, several strategies can be employed. Implementing a gyratory shaker during the production process to improve the contact between microorganisms and plant materials can significantly enhance amino acid production efficiency. The use of a soil sample from the topsoil of a forest may also improve the efficiency of amino acid production, as this type of soil is likely to contain more effective microorganisms.

The potential applications of this fermented mixture with amino acids are extensive. They can be effectively combined with biochar to produce biochar biocatalysts for organic fertilizer production [14, 15] creating enriched soil conditioners that enhance nutrient retention and promote sustainable agriculture [16]. Also, this type of liquid fertilizer can be easily incorporated into drip irrigation systems. This method ensures a consistent and precise delivery of nutrients to the root zone, promoting even growth and nutrient uptake by plants, and can be applied directly to the root zone by drenching the soil. It ensures that nutrients are delivered to the root system, where they can be readily absorbed. When applied correctly, it can reduce the risk of nutrient runoff and leaching compared to granular fertilizers. This can help minimize the environmental impact on water bodies. Furthermore, as additives in composting with other organic mixtures, these amino acid fertilizers can elevate the overall quality of compost, fostering healthier soil and increased crop yields. Proper storage is crucial for maintaining the quality and effectiveness of amino acid fertilizer. To prevent degradation and contamination, the fertilizer should be stored in compatible, non-reactive, and corrosion-resistant containers with tightly sealed lids [12]. A cool (4 °C is preferred) dark place is ideal for storage to protect the fertilizer from direct sunlight and high temperatures, which prevents degradation reactions [13]. It is vital to assess the economic feasibility of the fertilizer production process, aligning with sustainable practices by repurposing garden waste and utilizing agricultural land resources without incurring additional financial demands.

IV. CONCLUSION

This research has delved into the potential of utilizing *Gliricidia sepium* and *Tithonia diversifolia* as green materials for the production of amino acid fertilizers through microbial fermentation. The findings indicate the superior performance of *Gliricidia sepium* over *Tithonia diversifolia*, with significantly higher total nitrogen content and amino acid

concentration. The observation that the liquid sample contained suspends on day 7 suggests that the fermentation process was still ongoing. The fermentation conditions, such as temperature, pH, and nutrient availability, can have a significant impact on the production of amino acids and nitrogen. By optimizing these conditions, it is possible to further increase the concentration of these nutrients in the fertilizer. The potential applications for these amino acid fertilizers are diverse and far-reaching. They can be used to improve crop yields in a variety of settings, from smallholder farms in developing countries to large-scale agricultural operations. With ongoing adjustments and experimentation, there is substantial room for further refinement, leading to the creation of even more efficient and effective amino acid fertilizers.

ACKNOWLEDGMENT

This investigation received financial support from the Responsive Research Seed Grant (RRSG) 3rd cycle of the Sri Lanka Technological Campus. Grant No - RRSG.22.0811.2.

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2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

An Assessment of Water Footprint and Water Balance Towards Sustainable Water: A Case Study on Cut & Saw Apparel Facility in Sri Lanka

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***Abstract*—The water footprint and Water balance are comprehensive metrics that quantify the total volume of freshwater used across the entire supply chain of a product or service. By considering both direct and indirect water consumption, water input & outputs these assessments offer valuable insights into the environmental impact of various activities. The textile sector is water-intensive. Textile industries consume a large quantity of water and discharge polluted water to the environment. Therefore, water footprint and water balance assessment are important for textile processes (domestic and production) and products. In this study, the Bluewater footprint, greywater footprint, and water balance of the cut and saw facility in Sri Lanka on a single cut and sew garment factory in Sri Lanka are considered. Primary data was collected through on-site measurements of water consumption and interviews with key personnel within the selected factory. Data was collected monthly and analyzed to determine the components of the Water sources, identify areas of heightened water consumption, and assess the associated environmental impact. total Bluewater footprint in 2022 is 18422.06m^3/year. The total Greywater footprint in 2022 is 2956.57m^3/year This study will help policymakers, apparel brands, and industry management to take necessary steps to reduce water use and pollution in textile operations.**

Keywords—Water footprint, greywater, Bluewater, water balance

I. INTRODUCTION

Water is an indispensable resource, crucial for life and industrial processes. With an ever-growing global population and increasing industrialization, the demand for freshwater resources is intensifying. Sustainable water resource management is an urgent global concern. A key step in achieving sustainable water utilization is the assessment of water footprints.

A water footprint is a comprehensive metric that quantifies the total volume of freshwater used across the entire supply chain of a product or service. By considering both direct and indirect water consumption, water footprint assessment offers valuable insights into the environmental impact of various activities. The textile and apparel industry, renowned for its substantial water consumption, is an ideal context for this research. Sri Lanka, a major player in the global textile and apparel industry, presents an opportunity to explore the significance of water footprint assessment, particularly within the context of a cut-and-sew garment factory [1].

The concept of the water footprint was introduced by Hoekstra and Hung in 2002, gaining wide recognition as a valuable tool for quantifying water use and its environmental impacts. Different methods, including blue, green, and grey water components, have been developed for water footprint assessment. The textile and apparel industry is notorious for its significant water consumption and pollution, affecting every stage of the supply chain, from cotton cultivation to fabric dyeing and finishing. Numerous studies have highlighted the environmental and social consequences of excessive water use in this industry. Sri Lanka plays a pivotal role in the global textile and apparel market, significantly contributing to the nation's economy. However, the industry's rapid expansion has raised concerns about water resource management and pollution, necessitating water footprint assessments for sustainability. Sustainable water utilization is vital for environmental conservation and business continuity. Companies that actively manage their water footprints mitigate risks associated with water scarcity and compliance while enhancing their corporate image.

In a cut-and-sew garment factory, water plays a crucial role, despite the absence of printing, washing, and water used in the manufacturing process. While these specific processes are not employed in such facilities, water is still an essential resource utilized for various purposes. Research has shown that similar facilities often employ water for essential tasks such as cooling, sanitation, and general facility maintenance [2]. Water is used for cooling machinery and equipment, ensuring that they operate at optimal temperatures, which is crucial for maintaining production efficiency [3]. It is also essential for maintaining a clean and hygienic working environment in line with industry regulations [4]. This includes the cleaning and disinfection of production areas, restrooms, and common spaces to ensure a safe and healthy

workplace [2]. Additionally, research into comparable industrial settings indicates that water is employed for employee amenities like drinking fountains and bathroom facilities [5]. This usage aligns with providing a comfortable and conducive workspace for the factory's workforce.

II. Methodology

A. Data Collection

This study was concentrated on a single-cut-and-sew garment factory in Sri Lanka. Primary data was collected through on-site measurements of water consumption and interviews with key personnel within the selected factory [6]. As primary data facility main meter and submeter readings, no of working days, average monthly employees, drinking water quality reports, wastewater quality reports, and some water test parameters were taken.

Secondary data was sourced from government reports, industry publications, and relevant academic studies.

B. Water Footprint Assessment

Assessment of the Water footprint of each type is different depending on the sector. [7]. In This assessment, the Bluewater footprint, Greywater footprint, domestic water, and water balance (e.g., water used in domestic uses) were calculated. The Bluewater footprint was calculated using total extraction from the related water sources. The domestic water footprint was calculated based on the domestic consumption per person per day who worked in the selected factory [8].

C. Data Analysis

The collected data was thoroughly analyzed to determine the components of the water sources, identify areas of heightened water consumption, and assess the associated environmental impact.

III. Results

The Water balance analysis of 2022 is shown in Tab. 1

Table 1. Water Balance

Water Balance			
Input		***Output***	
Groundwater Extraction Tubewell"	4566.02	Production Washroom 01(handwashing and bathing purposes)	4956.98
Groundwater Extraction Dug Well 01	8121.02	Production Washroom 02(handwashing and bathing purposes)	317.67
Groundwater Extraction Dug Well 02	3306.98	Boiler (Steam for production)	481.2
Rainwater Meter	2428.04	Canteen	5234.03
Recycled water	2990.34	Toilet Flushing	6297.32
		Evaporative Coolers	3066.09
	21412.4		**20353.29**
		difference	**1059.11**
		% Difference	**5%**

Discrepancies between water input and output occur due to factors such as evaporation losses, leakages, and unaccounted water consumption through non-metered sections.

The primary sources of water supply, as depicted in Tab. 1, encompass groundwater, rainwater, and recycled water. These water sources cater to various needs, with domestic applications categorized into flushing, handwashing, cooking, and cleaning, while industrial purposes encompass steam generation for production and evaporative cooling, as outlined in Table 01.

Tab. 2 shows the Bluewater footprint of the facility in 2022

Table 2. Bluewater Footprint

Bluewater Footprint		
Month	***(f) Bluewater Footprint (m^3) ****	***Bluewater Footprint (L/day/person)***
January	1150.29	22.31
February	769.72	15.56
March	1157.15	19.98
April	1201.72	26.97
May	1980.97	34.38
June	2055.5	35.56
July	1426.68	24.63
August	1861.33	31.26
September	1353.44	27.17
October	1866.68	38.10
November	1801.15	36.95
December	1797.43	35.00
2022	18422.06	29.00

Sustainability is a key theme in water resource management, with a particular emphasis on Water footprint. Sources of Bluewater in the facility are groundwater and harvested rainwater. The total Bluewater footprint in 2022 is 18422.06 m^3/year. The daily Bluewater footprint per person is 29.00L/day/Person.

Tab. 3 shows the Greywater footprint of the facility in 2022.

Table 3. Greywater Footprint

Greywater Footprint Analysis		
Month	**(f) Greywater footprint (m3) ***	**Greywater Footprint (L/day/person)**
January	263.52266	5.11
February	283.57203	5.73
March	212.11304	3.66
April	275.38573	6.18
May	255.46141	4.43
June	235.43749	4.07
July	232.28302	4.01
August	239.06307	4.02
September	201.28245	4.04
October	249.55072	5.09
November	237.94056	4.88
December	270.96126	5.28
2022	**2956.5734**	**4.65**

The source of Greywater of the facility treated was wastewater portion of domestic use excluding treated recycled water used for flushing purposes. The total

Greywater footprint in 2022 is 2956.57m^3/year. The daily greywater footprint per person is 4.65/day/Person. The greywater footprint of the facility can be reduced via full utilization of treated wastewater from the sewage treatment plant (STP). The reduction of greywater footprint also effects on reduction of Bluewater footprint.

Tab. 4 shows the Domestic usage of the facility in 2022.

TABLE 4. DOMESTIC USAGE

Domestic Usage Analysis		
Month	***(f) Potable Water (Domestic Use) (m3) ****	***Daily Consumption per Employee (L/day/person)***
January	1310.18	25.41
February	1435.31	29.01
March	1515.45	26.16
April	873.39	19.60
May	1328.34	23.05
June	1606.89	27.80
July	1460.92	25.22
August	1451.01	24.37
September	1394.29	27.99
October	1378.2	28.13
November	1680.2	34.47
December	1371.82	26.72
2022	**16806**	**26.45**

The domestic water footprint of the facility is 26.45 L per day per employee according to Table 03. The monthly variation of water consumption due to fluctuation of No of workers worked per month, weather conditions, infrastructure changes, etc.

Several measures are implemented in the facility to optimize domestic water footprint such as water-saving fixtures used for the canteen, washrooms, dipping system, and automated dishwasher implanted for plate washing. Also conducting awareness via training, group activities, and using other communication tools such as PO systems, display boards, social media, etc.

Rainwater and Treated recycled water are the sustainable water sources that are utilized in the facility. Rainwater serves as an environmentally friendly resource and finds its application in evaporative cooling systems. Recycled water, on the other hand, constitutes the treated component of wastewater from sewage treatment plants (STPs). This treated water is integrated with groundwater for flushing purposes.

The following data shows the average number of employees worked and no of days worked in 2022

TABLE 5. NUMBER OF WORKERS AND WORKING DAYS

Avg No. of Employees	**No. of Days Worked**
2285.25	278

IV. CONCLUSION

This analysis shows that periodical monitoring and analysis of water consumption data can be used for environmental management system decision-making processes in the facility. Further, Critical consumption points identification, Water consumption patterns, and trend monitoring can be used towards shifting to sustainable water sources such as recycled water and rainwater to reduce groundwater extraction.

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2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

Green Synthesis of Silver Nanoparticles from Plant Extracts in Sri Lanka: A Review of Recent Advances and Bioactivities

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***Abstract*—There are numerous potential applications in green nanoparticle productions for biomedical and environmental fields. The synthesis of metal nanoparticles using plant extracts is considered one of the simplest, most convenient, cost-effective, and environmental friendly methods for avoiding the use of harmful chemicals. Silver, in particular, has long been recognized as a non-toxic and benign agent. Consequently, several eco-friendly processes for rapidly synthesizing silver nanoparticles have emerged, utilizing extracts from various plant parts such as the leaf, bark, and roots. In this review, we summarize the latest research on environmental friendly synthesis of silver nanoparticles (AgNPs) using diverse plant extracts available in Sri Lanka. Additionally, we discuss their potential bioactivities based on the literature.**

Keywords—Biosynthesis, silver nanoparticles, green nanotechnology

I. INTRODUCTION

Nanotechnology is a branch of technology that delves into the nano-scale, a realm characterized by its minute dimensions. This field has experienced a rapid surge in popularity over the past decade due to its wide range of applications. The use of silver to control infections was common in ancient civilizations. The use of silver for therapeutic purposes dates back to the Han Dynasty in China around 1500 B.C.E. During the Phoenician, Macedonian, and Persian empires, silver vessels and plates were commonly utilized [1]. The discovery of antibiotics in the early twentieth century halted the development of silver as an antibacterial agent. However, the recent rise in bacterial resistance to most antibiotics has prompted a reexamination of the possibilities of this ancient therapy, including research with patients utilizing colloidal silver and antibiotics [2]. Nanotechnology is a multidisciplinary field that was discovered in 1959 by Richard Feynman. Norio Tanaguchi defined nanotechnology as "being able to manipulate a single nanoscale object" in 1974. The term "nano" denotes one billionth of a unit, and a nanometer represents precisely that, one billionth of a meter. Nanoparticles (NPs), typically around 1-100 nanometers in size, consist of atomic or molecular scale solid particles with unique physical properties, attributable to their diminutive size and structure. Metal and metal oxide nanoparticles have garnered extensive attention in scientific and technological spheres. This heightened interest arises from their exceptional attributes, which include a high surface-to-volume ratio, excellent dispersion in solutions, and low toxicity. The formation of Ag-NPs has generated considerable interest due to their potential applications in catalysis, plasmonics, optoelectronics, biological sensors, antimicrobial activities, DNA sequencing, Surface-Enhanced Raman Scattering (SERS), climate change and contamination control, clean water technology, energy generation, and information storage and biomedical applications [3]. These bioactivities mainly show 1-100 nm range nanoparticles [4]. In biomedical applications, noble metal NPs such as copper, silver, platinum, gold, zinc, magnesium, and titanium have attracted a lot of attention for their diverse theragnostic properties [5].

There are two primary approaches for synthesizing nanoparticles, known as "top-down" and "bottom-up." In the top-down approach, which involves physical methods, the process begins with a bulk material that is broken down into minuscule particles through size reduction. This is achieved using a range of techniques, including pulse laser ablation, evaporation-condensation, ball milling, pulse wire discharge, and more. Conversely, the bottom-up approach involves the creation of nanoparticles through chemical and biological techniques. This method relies on the self-assembly of atoms into new nuclei, which subsequently grow into nanoscale particles [6].

Various chemical and physical methods have been employed in nanoparticle synthesis, but they often raise environmental concerns. In response, the concept of "green synthesis" has emerged, which involves utilizing materials such as plant extracts, plant biomass, animal proteins, agro-waste, pigments, bacteria, fungi, and viruses for nanoparticle production. This environmentally conscious approach seeks to minimize the ecological footprint of nanoparticle manufacturing [7]. Green tactics, for example, eliminate the need for costly chemicals, use a lot less energy, and produce byproducts and goods that are good for the environment [8]. The use of green nanotechnology in the biomedical, food, and agricultural sectors has a significant potential to improve the quality of life [9]. The overall function of the active components in a plant material determines how an herbal medication acts. That has a synergetic effect as a result of all the constituents. Developing base dosage forms for natural medicines using nanotechnology, such as solid lipid

nanoparticles (SLNs), polymeric nanoparticles (nanospheres and nanocapsules), pro-liposomes, liposomes, nano emulsions, etc., provides a great number of advantages in phyto formulation research. The improvement of solubility and bioavailability, stability, toxicity, pharmacological efficacy, prolonged delivery, stimulation of tissue macrophage circulation, and resistance to physical and chemical degradation are a few of these [10]. In nature, there are several ways to regulate the size and form of bio-nanoparticles. For instance, NPs with specified geometries are generated under rigorous genetic control. Biopolymers and polysaccharides had been used to make NPs, while water served as an environmentally friendly solvent and capping/reducing agent [11].

Due to its extensive range of applications in microbiology, chemistry, food technology, cell biology, pharmacology, and parasitology, silver nanoparticles (AgNPs) are among metal NPs that are among the most widely studied nanoparticles from the research community [12]. A variety of ways have been used to create silver nanoparticles, including the sol-gel method, hydrothermal method, chemical vapour deposition, thermal decomposition, microwave-assisted combustion method, etc. [13]. Considerable research has recently been conducted on the biogenic synthesis of silver nanoparticles (AgNPs), employing biomaterials such as plant extracts and microorganisms as reducing agents. AgNPs are created when various biomolecules, such as flavonoids, ketones, aldehydes, tannins, carboxylic acids, polyphenols, and the protein of plant extracts, oxidize Ag^{+} to Ag^{0} [14].

This review compiles data extracted from published research papers spanning the years 2015 to 2022, focusing on the biogenic synthesis of AgNPs in Sri Lanka. The objective of this review is to inspire researchers to explore the potential of natural resources in the country for silver nanoparticle production through the application of nanobiotechnology. In this review, we delve into the biogenic synthesis and the unique attributes of various plants employed in the creation of silver nanoparticles.

II. Biosynthesis of Silver Nanoparticles From Plant Extract

AgNPs are created by a simple, one-step process that does not produce harmful or expensive chemicals, making them safe, inexpensive, and environmentally friendly. In recent years, substantial research has been done on plants' ability to biosynthesize AgNPs of various sizes, shapes, and stabilities [13]. According to the literature, NPs have been biosynthesized in a variety of plant components, including leaves, roots, seeds, fruits, and stems. Figure 1 describes the common method of biosynthesis of AgNPs [15].

Different plant components are gathered from various sources, properly rinsed with ordinary water, and then washed again with distilled water to remove debris and other undesired items. The sections are then either used as it is to create the extract or dried and crushed into powder. To make the extract, the chopped or crushed plant components are placed in deionized water or alcohol and typically heated below 60 °C for a short period of time, as prolonged high-temperature heating may cause the phytochemicals in the biomass extract to decompose. AgNPs were created by adding plant extracts with various pH levels to solutions containing varying amounts of Ag salt as a metal precursor and then heating them at various temperatures [16]. Because the biomaterials in the extract work as both a reducing agent and a stabilizing agent for the synthesis of AgNPs, this method avoids the usage of chemical stabilizers [17]. Visual color alterations or UV-Vis spectroscopy, which clearly shows a sharp peak owing to surface plasmon resonance (SPR) of AgNPs at about 430-450 nm, can be used to track the development of AgNPs [18]. After the AgNPs have been successfully synthesized, the mixture is centrifuged at a high rpm to separate the NPs, followed by suitable cleaning with solvents and drying in a low-temperature oven [19].

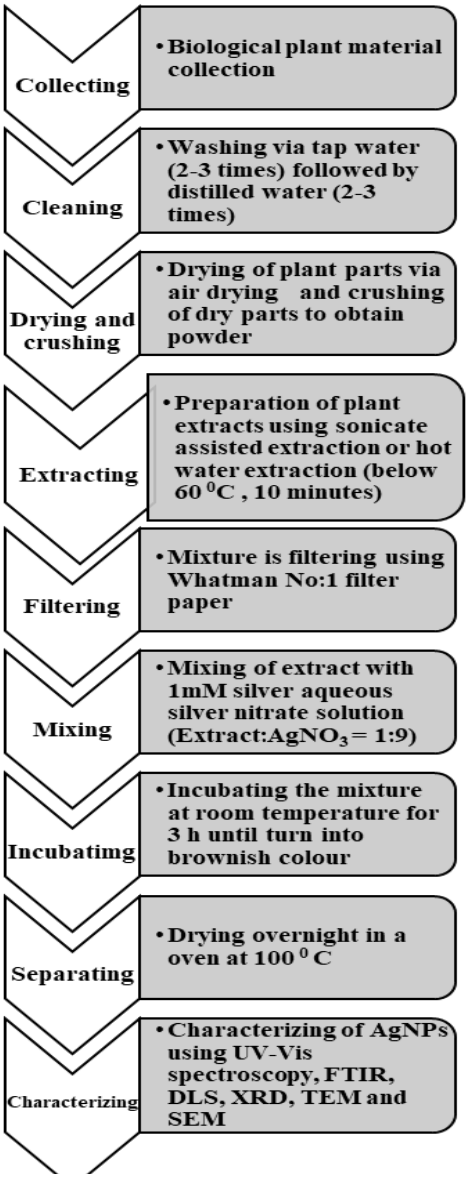

Fig. 1. Biosynthesis of silver nanoparticles using plant extracts

III. Bioactivities and Applications of Silver Nanoparticles

Biogenic production of metal and metal oxide NPs has attracted a lot of attention over the past few decades due to environmental concerns [13]. The purpose of this section is

to go over the various Sri Lankan plant component extracts that are used to create AgNPs and their bioactivities. There are few publications available in Sri Lanka for the green synthesis of AgNPs utilizing plant extracts.

Catharanthus roseus flower extracts mediated AgNPs were proved to exhibit excellent antioxidant, antimicrobial, and photocatalytic properties [16],[19]. *Azadiracta indica* (neem) aqueous leaf extract-mediated AgNPs were also found to be highly active against phytopathogenic fungi namely *Mucor* and *Colletritichum* [20]. Another study revealed that antimicrobial activity against *Enterococcus faecalis*, *Staphylococcus aureas*, *Staphylococcus saprophyticus*, and *Salmonella Typi* using *Plectranthus zeylanicus* AgNPs [21]. In this study antibacterial properties were reported against *Staphylococcus aureas* and *Enterococcus faecalis*. *Vigna Unguiculate* (Cowpea) leaf extract-mediated AgNPs were proven to exhibit excellent antioxidant and antimicrobial properties [22]. In another study, *Annona glabra* leaf mediated AgNPs exhibited photocatalytic activity [23] and mosquito larvicidal potential [24]. *Plumbago indica L*. root mediate AgNPs exhibited antimicrobial properties [25]. *Capsicum annuum* mediated AgNPs exhibited excellent antioxidant, antibacterial, and photocatalytic properties [26]. In another work *Chrysanthemum morifolium* Ramat varieties (brown, yellow, purple, pink, and salmon pink) produced AgNPs. Their antioxidant, photocatalytic, and antibacterial activities were reported [27]. Biosynthesized AgNPs suggest that they may be useful in the treatment of disorders caused by free radicals, environmental pollution, and antibiotic resistance. Furthermore, the antibacterial activity of produced AgNPs against *Escherichia coli* and *Staphylococcus aureus* showed. Another interesting work on synthesizing AgNPs using the peels of three citrus fruits (*Citrus tangerina, Citrus sinensis, and Citrus limon*) was reported [28]. In this study reported nanoparticles range in size from 5 to 80 nm and possess a variety of forms such as spherical, triangular, hexagonal, and rod. Furthermore, the antibacterial activity of AgNPs against Gram-negative (*Escherichia coli*) and Gram-positive (*Staphylococcus aureus*) bacteria reported. In another work, *Cinnamon verum* leaf extracts were utilized for the biosynthesis of AgNPs [27]. In this study antioxidant activity was determined by TPC, TFC, TAC, DPPH, and IC50 assays and showed a high antioxidant activity. Furthermore, the photocatalytic and antimicrobial activity reported for AgNPs. In recent times, highly antimicrobial AgNPs were synthesized using aqueous extract of *Eichhornia crassipes* (Mart.) Solms (water hyacinth) which is an invasive plant species found in Sri Lanka [29]. In another recent study, *Chnoospara minima* leaf extract was applied for the production of spherical AgNPs and showed inhibited proliferation of breast cancer cell lines [30]. To date, various plant extract has been utilized for the biosynthesis AgNPs in Sri Lanka (Table 1).

IV. Future Directions

The use of plants for the synthesis of green silver nanoparticles is an interesting and newly discovered area of nanotechnology that has a significant effect on the environment while helping in the long-term sustainability and advancement of nanoscience. Some of the potential uses of these green plant-based NPs include catalysis, cosmetics, medicine, agriculture, food packaging, water treatment, dye degradation, textile engineering, bioengineering sciences, sensors, imaging, biotechnology, electronics, optics, and other biological industries [31]. AgNPs are widely used in nanomedicine, including diagnostics, biomedicines, nanoelectronics, and molecular imaging, because of the enhanced electromagnetic field on their surface. AgNPs are widely used in food packaging to prevent microbiological illnesses because of their antibacterial properties [32]. AgNPs have been used in nanosensors for clinical diagnosis, contaminant analysis, flavor or color analysis, and water analysis [33]. AgNPs have also been used in agriculture. AgNPs can be supplied to crops in addition to pesticides to increase crop productivity. AgNPs are utilized in plant nutrition and disease defense [34]. AgNPs are commonly used as antifungal, antibacterial, anti-inflammatory, and antiviral medicinal agents. AgNPs might be the future impetus for drug delivery to lower drug doses, increase specificity, and reduce toxicity because of their antibacterial properties [35]. These green NPs applications might be further developed in a variety of ways, including phytopathogen treatment in agriculture or water disinfection for environmental cleanup [31]. This environmentally friendly method of producing AgNPs is gaining traction and is anticipated to experience substantial growth in the coming years. In Sri Lanka, several reports have been published on the synthesis of silver nanoparticles using plant extracts, as previously discussed. Nevertheless, there is an unmet need for a commercially viable, cost-effective, and environmentally friendly approach to explore the potential of natural reducing agents in generating silver nanoparticles, which remains largely unexplored. Hence, there is a need for comprehensive research to fully explore the potentials and applications related to the biosynthesis of silver nanoparticles using plant extracts in Sri Lanka. There is a large difference in the chemical contents of plant extracts of the same species gathered from different parts of the world, which may result in different results in different laboratories. This is the major disadvantage of synthesizing silver nanoparticles with plant extracts as reducing and stabilizing agents, and it must be resolved.

The overexploitation of natural resources can result in habitat destruction and the loss of biodiversity. Hence, it is crucial to conduct routine monitoring and characterization of silver nanoparticles produced via green synthesis methods to guarantee their stability and safety. Early detection and resolution of any changes in their properties that might heighten their environmental risk are imperative. While the green synthesis of nanoscale metals holds significant promise, it is constrained by factors such as material selection, synthesis conditions, product quality control, and applications. These factors present challenges to industrial-scale manufacturing and the widespread application of green-synthesized nanoscale metals [36]. The energy consumed during the synthesis process, especially in large-scale production, may still contribute to carbon emissions and environmental impact. To mitigate this, it is essential to employ energy-efficient methods and utilize renewable energy sources to reduce the carbon footprint. Additionally,

source materials for green synthesis, such as plant extracts or microbes, should be harvested or cultivated sustainably [36].

Reliable toxicity data is currently lacking, which leaves a knowledge gap regarding the potential harm to human health. While green synthesis methods are generally characterized by the use of less harmful reagents, silver nanoparticles themselves can present ecological risks. Their small size and high surface area can result in heightened reactivity, potentially leading to toxicity in aquatic and terrestrial organisms. As a result, it becomes imperative to undertake thorough toxicity studies to evaluate their impact on diverse ecosystems [37]. Large amounts of silver products released into the environment may disrupt the microbiological ecosystem and potentially lead to bacterial resistance to silver. As a result, other means of sanitization, such as the use of alcohol or bleach for domestic purposes, or the use of 'fixed' silver-containing surfaces that decrease the possibility of environmental discharge, should be considered. The synthesis process could generate wastewater containing unreacted chemicals or byproducts. Ensuring the proper disposal and treatment of this wastewater is crucial to prevent the contamination of natural water bodies. To effectively remove or neutralize any contaminants, advanced treatment methods like filtration, chemical precipitation, or bioremediation may be required [38].

V. Conclusion

The growing interest in green chemistry and nanotechnology in recent decades has spurred the utilization of eco-friendly synthetic approaches for nanomaterial production through plant extracts, microbes, and other sustainable means. Researchers have increasingly focused on the green synthesis of nanoparticles, leveraging environmentally safe methodologies. Plant extract-mediated nanoparticles, due to their cost-effectiveness, harmlessness, availability, and environmental friendliness, have garnered considerable attention among researchers exploring their potential applications in various fields. However, in Sri Lanka, these applications are still in their nascent stages. In this review article, the focus is on the plant-based green synthesis of AgNPs, encompassing aspects such as production, characterization, and potential applications. There is a significant gap in the quest for a commercially viable, cost-effective, and environmentally friendly approach to fully explore the untapped potential of natural reducing agents for silver nanoparticle production in Sri Lanka. This gap highlights the need for comprehensive research to uncover the potentials and applications associated with biosynthesizing silver nanoparticles using plant extracts in Sri Lanka.

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TABLE 1: PLANT EXTRACTS EMPLOYED IN GREEN SYNTHESIS OF SILVER NANOPARTICLES AND THEIR BIOLOGICAL ACTIVITIES REPORTED IN SRI LANKA

Plants		**Plant parts**	**Synthesized AgNP Characterization methods**	**Synthesized AgNP size range and shape**	**Bioactivity / Application**	**Reported Bioactivity**	**References**
Scientific name	***Common name***						
Catharanthus roseus	periwinkle, Madagascar periwinkle, graveyard plant	Flower	UV/Vis spectro-photometric analysis (UV-VIS), Scanning electron microscopy (SEM)	0 – 30 nm, spherical	Antioxidant properties	Total flavonoid content (TFC), total phenolic content (TPC), total antioxidant activity (TAC), ferric-reducing antioxidant properties (FRAP) and DPPH	[17] [39]
					Antimicrobial properties	Antimicrobial activity against Gram-negative *Escherichia coli* using the agar well diffusion method	
					Photocatalytic properties	The removal of methyl orange dye from an aqueous solution under sunlight irradiation in the presence of $NaBH_4$ catalyst (AgNPs concentrations 5000 ppm and 333 ppm)	
Capsicum annuum	Chili, Pepper	Seeds	UV-Vis spectra	25 - 75 nm, spherical	Antioxidant properties	TAC and DPPH assay	[26]
					Antibacterial	Assessed against *Escherichia coli* and *Staphylococcus aureus.*	
					Photocatalytic properties	Assessed using methylene blue (AgNPs concentrations 6350 ppm)	
Chrysanthemum morifolium	Chrysanthemum, Mums	Flowers	UV-VIS, SEM	40 ± 1.2 nm, spherical	Antioxidant activities	TFC, TPC, TAC, DPPH, FRAP	[27]
					Photocatalytic activities	Assessed by the degradation of the model dye methylene blue. (AgNPs concentrations 212 ppm and 3175 ppm)	
					Antibacterial activities	determined on *Staphylococcus aureus* and *Escherichia coli*	
Vigna Unguiculate	cowpeas	Leaves	UV-VIS, SEM	40 nm, spherical	Antioxidant properties	TFC, TPC, TAC, FRAP, ABTS and DPPH assays	[22]
					Antibacterial activities	well diffusion method using gram positive (*Staphylococus aureus*) and gram negative (*Escherichia coli*) bacteria	
Annona glabra	Alligator Apple	Leaves	UV-VIS, SEM	10 - 190 nm, spherical	Photocatalytic Activity	Using Methylene blue solution	[23]
			(UV-VIS), (SEM), dynamic light scattering (DLS) (FTIR)	10 - 100 nm, spherical	Mosquito larvicidal potential	Larvicidal bioassays	[24]
Azadiracta indica	Neem Tree	Leaves	UV-VIS	-	Antimicrobial properties	Be highly active against phytopathogenic fungi namely *Mucor* and *Colletritichum* (greatly suppress concentration of AgNPs 25 mg/1.5)	[20]

Plectranthus zeylanicus	Iruveriya, Variegated Indian Borage	Plant	UV-VIS, SEM	-	Antibacterial activities	Antibacterial potential against *Staphyococcus aureus*, *Enterococcus faecalis* (Minimum concentration range 125-250 µg/mL)	[21]
						Disc diffusion and broth microdilution method against both gram negative and positive bacteria	[40]
Plumbago indica L.	Scarlett Leadwort,Rathnitul	Roots	GC/ MS, Fourier transform infrared spectroscopy (FT-IR) and UV-Vis spectra	-	Antimicrobial activity	Antimicrobial assay	[25]
Citrus tangerina, Citrus sinensis, and Citrus limon	Citrus	Citrus peel	UV-VIS, (FTIR), and transmission electron microscopy (TEM)	5 - 80 nm triangular, rod, near spherical, spherical, and hexagonal shapes	Antibacterial activity	Antibacterial activity against Gram-negative (*Escherichia coli)* and Gram-positive (*Staphylococcus aureus*) bacteria using a well diffusion method.	[28]
Eichhornia crassipes (Mart.) Solms	Water hyacinth	Plant	UV-VIS, SEM and energy dispersive X-ray	41 - 103 nm, spherical	Antimicrobial activity	Antimicrobial activity tested against *Escherichia coli*, *Staphylococcus aureus* and three different MRSA strains by using broth- micro dilution method.	[29]
Munronia pinnata	Bin kohomba	Stem and leaves	UV-VIS, SEM	39.41 - 82.08 nm spherical	Antimicrobial activity	Antimicrobial activity tested against both gram positive (*Staphylococcus aureus, Bacillus subtilis*) and gram negative bacteria (*Escherichia coli*), using broth dilution (MIC) method (Inhibition concentration range is 0.250 µg/mL- 0.750 µg/mL of Ag NPs concentration)	[30]
Rhipsalis baccifera	Mistletoe cactus	stem					
Stachytarphera indica	Snake weed	Leaves and stem					
Chnoospara minima	Brown algae	Leaves	FTIR, UV-VIS, SEM, DLS, Zeta Potential, and Energy Dispersive X-ray	-	Anti-cancer activity	Inhibit proliferation of breast cancer cell lines	[41]

2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

Enhancing Heavy Metal Removal from Wastewater Using Low-Cost Adsorbents: A Review

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***Abstract*—Heavy metals are significant contaminants in wastewater, posing a serious threat to the environment and human health due to their non-biodegradable nature and ability to accumulate in living tissues. This issue is particularly relevant in the context of wastewater generated from domestic, industrial, and agricultural sources. Among these, the industrial and agricultural sectors are primary contributors to heavy metal discharge into water bodies. Therefore, finding cost-effective methods to remove heavy metals from wastewater is of utmost importance. Adsorption emerges as a promising wastewater treatment technique, valued for its cost-effectiveness and availability. This review article aims to consolidate scattered information on the use of low-cost adsorbents for heavy metal removal from wastewater, categorizing them into natural, industrial, and agricultural waste-based adsorbents. Initially, the article briefly discusses the sources of wastewater generation and highlights the adverse effects of heavy metals on human health when present in water. Subsequently, it delves into the application of low-cost adsorbents as effective means of removing heavy metals from wastewater. Finally, the article explores factors influencing the adsorption capacities of these selected low-cost adsorbents and presents methods for enhancing their adsorption capabilities.**

Keywords—Adsorbents, heavy metal, wastewater, adsorption

I. INTRODUCTION

Water, indisputably the planet's most vital resource, finds itself increasingly imperiled in the face of escalating global development. The persistent rise in water pollution levels not only engenders a shortage of potable water but also begets widespread suffering for a multitude of individuals worldwide. Over the years, the quality of water has deteriorated mainly due to anthropogenic activities, population growth, unplanned urbanization, rapid industrialization, and unskilled utilization of natural water resources [1]. Wastewater often contains harmful pathogens, chemicals, heavy metals, and various other contaminants that can pose serious health risks to human health if they are released into the environment without any treatment. Furthermore, untreated wastewater can have detrimental effects on aquatic ecosystems. So, treating wastewater before it contaminates the surface and groundwater bodies is essential. According to Manasa & Mehta [2] identifying sources of wastewater and its polluting components is essential to save water bodies. The same authors explained that domestic, agricultural, and industrial sectors are the major sources of generating wastewater. Among the significant contaminants in wastewater, heavy metals take a prominent place. Kuldeyev et al [3] explain that the numerous industrial operations, such as fuel and energy generation, iron and steel production, metallurgy, and metal surface treatment, generate waste materials laden with diverse heavy metals. Furthermore, Evans et al [4] described that water pollution has increased due to the use of chemicals including pharmaceuticals for agricultural activities. In most of the countries, discharging standards for water quality parameters have been introduced to prevent water pollution. Regrettably, in several nations, these byproducts are still discharged into the environment without undergoing subsequent treatment.

The escalating global concerns surrounding water pollution have necessitated innovative and cost-effective solutions for enhancing the removal of heavy metals from wastewater. Heavy metals, such as lead, cadmium, chromium, and mercury, are notorious pollutants known for their adverse health effects on both humans and the environment. The increasing anthropogenic activities, urbanization, and industrialization have amplified the discharge of heavy metals into our water bodies, posing a grave threat to water quality and ecosystem health.

This article's main goal is to comprehensively review recent research published on Google Scholar from 1998 to 2023 regarding the utilization of low-cost adsorbents for wastewater treatment, with a primary focus on removing heavy metals. It seeks to provide a detailed summary of these research findings. Additionally, this review delves into the literature to examine the removal efficiencies of various heavy metals using different low-cost adsorbents, the treatment techniques employed, and the chemical properties of these adsorbents. Moreover, the article addresses the key limitations associated with using low-cost adsorbents in wastewater treatment and briefly outlines future directions for incorporating low-cost materials into wastewater treatment systems.

II. HEAVY METALS IN WASTEWATER

Heavy metal is one of the most important pollutants present in the wastewater. According to Tripathi and Ranjan [5] heavy metals present in the wastewater are persistent and non-biodegradable and can be easily absorbed by living cells. Furthermore, they explained that there exists a group of metals, approximately 20 in number, (Pb, Hg, Cd, As, Cr, Tl, Be, Ba, Ra, U, Pu, Ni, Zn, Cu, Ag, Au, Pd, Co, Mn, and Fe) that exhibit high persistence and are resistant to degradation or destruction. These metals, such as Mercury (Hg), Lead

(Pb), Cadmium (Cd), Chromium (Cr [VI]), Zinc (Zn), Arsenic (As), Nickel (Ni), among others, are considered toxic heavy metals from an ecotoxicological standpoint. So, the presence of heavy metal ions in water is very harmful to life [6]. The consumption of contaminated water with heavy metals results in serious human health issues such as cardiovascular disorders, neural damage, renal injuries, risk of cancer, and diabetes.

Zinc (Zn) is a vital heavy metal for human health as it plays a crucial role in regulating various biological processes within the body. However, excessive concentrations of Zn can lead to severe health issues such as skin irritation, nausea, and anemia. Similarly, an excess of copper (Cu) in the body can result in symptoms like vomiting, convulsions, and even fatalities. Elevated levels of nickel (Ni) can lead to serious lung and kidney problems, while a high concentration of mercury (Hg) can weaken pulmonary and kidney function. Lead (Pb) is another heavy metal that poses health risks, damaging the kidneys, liver, and reproductive system. To prevent these health hazards, it is imperative to remove heavy metals from wastewater before they contaminate surface and groundwater resources [7]. The discharge of untreated wastewater containing heavy metals is a significant environmental threat and a health risk to humans. It is imperative to reduce or completely eliminate harmful metal levels in wastewater before their release into the environment [8]. Various methods have been explored for the removal of heavy metals from wastewater, including electrocoagulation, magnetic field techniques, membrane filtration, and adsorption [9]. Among these approaches, numerous studies have emphasized the use of low-cost adsorbents for heavy metal removal due to their cost-effectiveness and ease of implementation.

III. Adsorption

Adsorption is considered a more efficient and economical approach in comparison to alternative technologies for treating wastewater and removing heavy metals. It is the process by which a liquid solute forms a molecular or atomic film on the surface of a solid adsorbent (the adsorbate). Adsorbents can be categorized into three groups: synthetic, natural, and semi-synthetic [10]. The absorption process can be described using two types physical adsorption and chemical adsorption depending upon the intermolecular attractive forces. Physical adsorption refers to a mechanism whereby the adsorbate molecules are bound to the surface of an adsorbent through the influence of van der Waals forces of attraction. In chemical adsorption, the strong interaction between the adsorbate and the substrate surface creates new types of electronic bonds (Covalent, Ionic) [5]. When there exists a disparity in concentration between the substance being adsorbed (adsorbate) and the material it is adhering to (adsorbent), the adsorbate molecules in the solution migrate and attach themselves to the surface of the adsorbent [10]. By now, the adsorption process is widely used for identifying the applicability of various adsorbents to remove multiple pollutants from wastewater by identifying the removal efficiencies for relevant adsorbates. According to Raj et al, (2019) there are several mathematical models to describe the kinetics of adsorption. These models are used to describe the kinetic process of adsorption and the adsorption mechanism [11]. Furthermore, adsorption isotherms are used to investigate the mechanics of adsorption[12]. The equilibrium between the adsorbed and unabsorbed concentrations at a particular temperature is described by an adsorption isotherm [13]. Langmuir isotherm model and the Freundlich isotherm model are the widely used isotherm model for investigating the adsorption mechanisms of adsorbents [12].

IV. Low-Cost Adsorbents and Their Applicability to remove Heavy Metals

Low-cost adsorbents, encompassing natural materials, industrial wastes, and by-products, have emerged as a viable and cost-effective solution for treating wastewater contaminated with heavy metal pollutants. Researchers in the past have frequently turned to low-cost materials, either in their natural state or after suitable modifications, for wastewater treatment.

A. Natural Adsorbents

When contemplating natural adsorbents for wastewater treatment, they have garnered considerable attention as cost-effective alternatives worth investigating. Among these natural adsorbents, natural zeolite stands out as a well-established and economically viable option. Zeolites exhibit exceptional proficiency in the removal of cadmium (more than 80%) due to their composition, consisting of hydrated aluminosilicate minerals formed by interconnected tetrahedral structures of alumina (AlO_4) and silica (SiO_4) moieties [14]. Natural zeolites can be further enhanced through various methods, including acid treatment, ion exchange, and surfactant functionalization. These modifications substantially augment their adsorption capacity, particularly for organic substances and anions. Moreover, several researchers have explored the remarkable capacity of human hair to effectively eliminate heavy metals from wastewater. For instance, Asubiojo and Ajelabi[15] conducted a study revealing that human hair exhibited impressive removal efficiencies for heavy metals such as zinc (Zn), lead (Pb), iron (Fe), and manganese (Mn), with removal rates ranging from 64.3% to 92.4%.

Additionally, biosorbents have emerged as cost-effective and environmentally friendly materials for wastewater treatment in previous studies. Ghasemi et al.[16] conducted research in which they utilized Sargassum hystrix algae, sourced from the Persian Gulf coastline in Bushehr, Iran, as a biosorbent to extract Fe (II) from aqueous solutions. Furthermore, the capacity of cuttlebone to adsorb lead (II) and copper (II) from aqueous solutions was identified, specifically focusing on the dead biomass of cuttlefish bone. The results demonstrated the significant potential of cuttlebone for self-purification in marine environments and its efficiency as a medium for removing metal ions from water and wastewater. This underscores its promise as an adsorbent for both Pb^{2+} and Cu^{2+} ions. Notably, cuttlebone exhibited maximum adsorption capacities (qm) of 45.9 mg/g for Pb^{2+} and 39.9 mg/g for Cu^{2+}, highlighting its effectiveness in metal ion adsorption [17]. Furthermore, it is worth noting that natural red earth and peat have been recognized as highly efficient and cost-effective adsorbents for the removal of lead (Pb) from landfill leachate, as demonstrated by Abhayawardana's research in 2015[18]. This finding

underscores the practical and sustainable potential of these materials in mitigating the environmental impact of wastewater contaminants.

B. Industrial Wastes

When examining industrial wastes, it's important to note that they encompass the byproducts and residues generated during various manufacturing and production processes across industries. This review paper primarily focuses on industrial wastes resulting from construction and demolition activities. Building waste materials, such as Portland cement, fine and coarse aggregates, and admixtures like fly ash and plasticizers, exhibit a notable capacity for the removal of heavy metals. Additionally, roof waste and brick and mortar waste, containing clay, have demonstrated high adsorption capacities for heavy metals. One particularly noteworthy industrial waste is fly ash, a by-product of coal combustion. Researchers have been exploring its potential as a cost-effective method for wastewater treatment. For instance, Maiti et al[19] reported a remarkable 93.8% removal efficiency for copper at an initial concentration of 43 mg/L and a pH of 6, using a fly ash dosage of 63 g/L. Similarly, Hegazi[20] found that fly ash exhibited high removal efficiencies for multiple inorganic pollutants when dosed at 60 g/L, highlighting its effectiveness. Moreover, Maiti et al.[19] pointed out that fly ash is particularly well-suited for treating acidic wastewater generated by industries such as electroplating, fertilizer production, copper smelting, and acid mine drainage. Detailed information regarding selected industrial wastes for heavy metal treatment in wastewater can be found in Table 1.

C. Agricultural Wastes

Agricultural wastes refer to the byproducts and residues generated within the agricultural sector during various farming activities and crop production processes. These wastes encompass a diverse array of materials, including crop residues, animal manure, agricultural runoff, and discarded packaging materials. In past research, agricultural wastes have been extensively employed in wastewater treatment processes. Specifically, materials such as peanut skin, wheat bran, paddy husk, bagasse, and coconut coir pith have found widespread application in the removal of heavy metals from wastewater. Table 1 depicts detailed information on the applicability of low-cost adsorbents for heavy metal removal from wastewater highlighting their adsorption capacities, removal efficiencies, treatment techniques, and chemical properties of the adsorbents by categorizing them as natural adsorbents, industrial wastes, and agricultural wastes. The utilization of such low-cost adsorbents presents a promising avenue for the development of efficient and economical strategies for wastewater treatment and environmental protection.

After reviewing these past researches, it's clear that almost all the low-cost materials showed a good removal efficiency for Pb. Notably, zeolite and brick clay have exhibited outstanding 100% removal efficiency for Pb, while several other selected low-cost adsorbents have demonstrated impressive removal efficiencies for Pb (Table 1). Additionally, clay mineral adsorbents have been widely used for heavy metal removal processes due to their higher adsorption capacities. Furthermore, natural and agricultural adsorbents such as peanut skin, wheat bran, paddy husk, human hair & bagasse showed higher removal efficiencies for heavy metals (Zn, Pb, Fe & Mn) and their removal efficiencies varied from 64.3 to 97.8%, 45.0 to 93.5%, 64.3 to 91.7%, 64.3 to 92.4% and 62.5 to 98.5% respectively[15]. Column experiments and batch sorption experiments have emerged as the predominant methodologies for assessing the efficacy of adsorption as a treatment process. In response to the pressing global environmental concerns associated with industrial wastewater, researchers have increasingly focused their efforts on the treatment of heavy metals within this particular category of wastewater. This emphasis on heavy metal treatment stems from the substantial environmental impact that industrial wastewater can have on a global scale.

Moreover, a significant trend observed among researchers is the enhanced adsorption capacity of modified low-cost materials compared to their natural counterparts, particularly in the removal of heavy metals. For instance, Nhapi et al. [21] found that activated rice husk (ARH) consistently exhibited superior removal efficiencies for heavy metals such as Pb, Cd, Cu, and Zn when compared to carbonized rice husk (CRH).

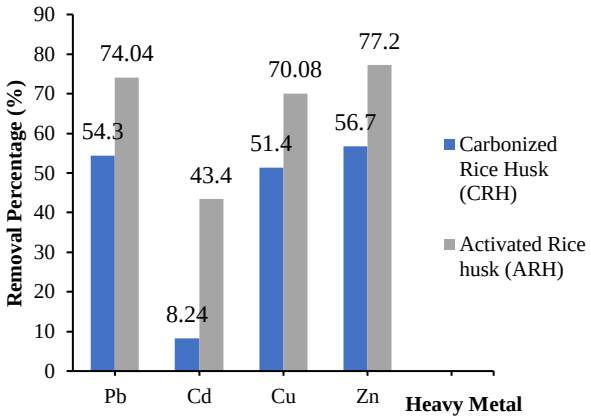

Fig. 1: Comparison of heavy metal removal efficiencies between CRH & ARH

Fig. 1 provides a visual representation of the comparative removal efficiencies for Pb, Cd, Cu, and Zn between ARH and CRH. This trend underscores the potential of modified low-cost materials as promising alternatives for efficient heavy metal adsorption and it illustrates that ARH consistently outperforms CRH in terms of removal efficiencies for relevant heavy metals. Furthermore, thermally modified zeolite exhibits superior heavy metal removal efficiencies compared to natural zeolite, which displays lower removal rates in comparison.

V. Influential Factors in the Adsorption of Heavy Metals onto Adsorbents

The efficiency of heavy metal adsorption by various low-cost adsorbents is influenced by several key factors. These factors encompass the particle size distribution, the duration of contact between the adsorbent and the metal ions, the temperature at which the adsorption process is conducted, the pH level of the solution, the initial concentration of metal ions in the solution, and the adsorbent dosage. In most cases

adsorption capacities of adsorbents increase when particle size reduces because reducing the particle size leads to an increase in the surface area of the adsorbent material, which in turn enhances the contact area available for interactions with the target molecules in the wastewater.

A. Effect of Contact Time

Effect of contact time is one of the most important characteristics that affects the adsorption process. The main objective of obtaining optimal contact time is to identify the best contact time for the adsorption of relevant parameters onto the adsorbent. Optimum contact time varies depending on the type of the adsorbent and the adsorbate. Normally after the optimum contact time is achieved, there cannot be a significant change of the equilibrium concentration. As examples, Desta (2013) identified the optimum contact time for the removal of heavy metals using agricultural wastes. At initially adsorption rate was increased rapidly for all the heavy metals (Ni, Cd, Cu, Cr, Pb), and after 60 min removal efficiencies were reached to an equilibrium value[22]. Adsorption of Cd (II) onto bentonite was studied by Chen et al (2011) and observed that within the first 10 min 95% of fast adsorption showed by bentonite. The optimum contact time was captured with 1h and after that it reached equilibrium concentration[23]. Similarly, Chen et al. (2011) investigated the adsorption of Cd (II) onto bentonite. Their study revealed that within the first 10 minutes, bentonite exhibited rapid adsorption, with 95% of the adsorption occurring during this period. The optimal contact time was determined to be 1 hour, after which the concentration of Cd (II) in the solution reached equilibrium [23].

B. Effect of Temperature

Numerous researchers have explored the influence of temperature on the removal of heavy metal concentrations. For instance, Vinayakamoorththy (2019) observed that the total iron removal capacity, when recycling building waste, increased with higher temperatures [24]. In another study, Desta conducted batch sorption experiments to investigate the removal of metal ions using agricultural waste. They varied the temperature of the solution within the range of 298K to 343K (298, 308, 318, 328, 343K). The results indicated a notable increase in metal adsorption as the temperature rose, demonstrating a clear correlation between temperature and enhanced metal removal efficiency [22].

C. Effect of pH of the Solution

According to the published research, pH of the solution affected the proportion of metal ions adsorption. Vinayakamoorththy et al (2019) carried out batch sorption experiments for the removal of total iron from the landfill leachate using recycled building wastes by varying initial pH. The highest observed total iron adsorption occurred at a pH level of 8 [24]. However, when investigating the influence of initial pH on heavy metal adsorption using agricultural waste, Desta found that adsorption significantly decreased when the initial pH of the solution exceeded 6.5 [22]. Similarly, Gebretsadik et al. (2020) explored the relationship between initial pH and heavy metal adsorption by low-cost adsorbents. Their batch experiments, where they varied the initial pH of the solution, revealed that the adsorption percentage increased in the order of Cr > Pb > Cd as pH levels increased [25]. Furthermore, Panda et al. (2017) examined the impact of pH on the removal of Cr using industrial waste. They varied the pH of the solution to understand its effect on the adsorption process. Their findings indicated a rapid decrease in adsorption percentage once the pH of the solution reached 2. This decline was attributed to the weakening of the electrostatic force of attraction between oppositely charged adsorbate and adsorbent. The reduction in this electrostatic force resulted in a decreased adsorption capacity [26].

D. Effect of Initial Ion Concentration

Many researchers have demonstrated that the adsorption efficiency is influenced by the initial ion concentration of the solution. For instance, Gebretsadik et al. (2020) noted that the removal efficiencies of Cr, Cd, and Pb rapidly increased with higher initial concentrations of these heavy metals. The authors attributed this phenomenon to the greater number of collisions between the biosorbent and the metal ions as the initial metal ion concentration increased. This increased collision frequency resulted in enhanced adsorption efficiency [25]. Contrastingly, Panda et al. (2017) observed a decrease in the ability to remove Cr using industrial waste as the initial Cr ion concentration increased. They attributed this decline to a reduction in the availability of adsorption sites when the initial concentration was high. This decrease in available adsorption sites led to a lower removal efficiency [26].

E. Effect of Adsorbent Dose

The quantity of adsorbent dose plays a crucial role in adsorption, particularly in batch sorption experiments. As the amount of adsorbent dose increases, the removal percentage of heavy metals typically rises. For instance, Desta (2013) investigated the effect of increasing the amount of agricultural waste on the removal efficiency of Ni, Cu, Cr, and Pb, revealing that the removal efficiency of these metals improved as the quantity of agricultural waste increased [22]. Similarly, Gebretsadik et al. (2020) aimed to enhance the removal efficiencies of three heavy metals (Cr, Cd, Pb) using low-cost adsorbents. They systematically increased the adsorbent dosage from 0.1g to 4g, while keeping adsorbate concentration and pH constant.

TABLE 1: DETAILED SUMMARY OF HEAVY METAL REMOVAL USING LOW-COST ADSORBENTS

Type of the adsorbent	Adsorbent	Chemical Properties of the adsorbent	Tested Wastewater Type	Tested Heavy metals	Reported Average Removal Efficiencies	Treatment Technique/Process	References
Natural Adsorbents	Modified natural zeolite ($treated\ at$ 550℃)	SiO_2 = 69.31%, Al_2O_3 = 13.11%, Fe_2O_3=1.31%, CaO =2.07%, MgO=1.13%, Na_2O=0.52%, K_2O=2.83%, SO_3=0.10%, H_2O=6.88%, Si/Al=4.66%	Synthetic solutions of heavy metal ions	Cu, Cd, Pb, Ni	99%, 99%, 100%, 87%	Adsorption	[3]
	Natural Zeolite		Wastewater	Co, Cu, Zn, Mn	77.96%, 66.10%, 45.96%, 19.84%	Batch sorption Experiments	[27]
	Natural red earth (NRE) and peat	NRE is composed of high Fe^{3+}, up to 6 %. NRE mainly consists of S i0 $_2$ (54.15 %), AI_2O_3 (20.73 %) and Fe_3 0 $_2$	Landfill Leachate	Pb	73% and 64%	Batch Sorption Experiments	[18]
	Human Hair	45 % Carbon, 28 % Oxygen, 15 % Nitrogen, 7 % Hydrogen and 5 % Sulphur.	Industrial Wastewater (Battery)	Zn, Pb & Fe	72.3%, 72.8% & 91.3%	Column Experiments	[15]
Industrial Wastes	Fly Ash	SiO_2= 40.34%, AI_20_3= 27.59%, Fe_20_3= 9.75% CaO =2.49%, MgO =0.42%, Na_20= 0,62%, K_20= 2,36% TiO_2 =2.60%	Industrial Wastewater	Fe, Pb, Cd, Cu, Ni	86.757%, 76.068%, 73.542%, 98.545%, 96.034%	Adsorption (Desorption test - To identify the amount of adsorbed adsorbate)	[20]
			Municipal wastewater treatment plant (SWTP) effluent	Cu, Pb	42%, 85%	Adsorption	[28]
	Thermally modified Concrete Waste	SiO_2 =33.04%, Al_2O_3=6.85%, Fe_2O_3=4.66%, CaO =45.86%, MgO =3.21%, SO_3=2.16%,K_2O=1.60%, Na_2O=0.18%, Other=2.44%	Aqueous solutions	Pb	92.96%	Batch Sorption Experiments	[29]
	Brick clay	Brick consists of clay which can remove the pb^{2+} ions.	Metal ion solution	Cu, Cd, Cr, Pb, Zn, Ni	100%, 100%, 100%, 100%, 94%, 94%	Column Experiments	[30]
	Concrete waste, flooring waste, brick and mortar waste, roofing waste		Landfill Leachate	Total Iron	99.6%, 97.8%, 97.9% and 95.3%	Batch Sorption Experiments	[24]
Agricultural Wastes	Sugarcane Bagasse	42% Cellulose, 25% hemicellulose, and 20% lignin	Textile wastewater	Fe, Zn	91%, 89%	Batch Sorption Experiments	[31]
			Untreated wastewater channel of Kaduna Refinery and Petrochemical Company (KRPC), Kaduna State Nigeria	Pb, Ni	89.31%, 96.33%	Batch Sorption Experiments	[32]
	Rice Husk	Rice Husk: 32% Cellulose, 21.3%Hemicellulose, 21.4% lignin, 1.82% Extractives, 8.11% Water	Synthetic wastewater	Fe, Pb, Cd, Cu, Ni	99.25%, 87.17% 67.91%, 98.17%, 96.95%	Adsorption Batch Experiments	[20]

			Metal ion solution	Cu, Cd, Cr, Pb, Zn, Ni	32%, 13%, 12%, 64%, 11%, 13%	Column Experiments	[30]
	Carbonized Rice Husk (CRH)		Textile wastewater	Pb, Cd, Cu, Zn	54.3%, 8.24%, 51.4% and 56.7%	Batch Experiments & Column Test	[21]
	Activated Rice Husk (ARH)		Textile wastewater	Pb, Cd, Cu, Zn	74.04%, 43.4%, 70.08% and 77.2%	Batch Experiments & Column Test	[21]
	Coconut wastes	20–30 wt% cellulose, 15–30 wt% hemicellulose, and nearly 50 wt% lignin	Common Effluent Treatment Plant (CETP)	Cu, Ni, Cd	100%, 99.9%, 99.57%	Adsorption	[33], [34]
	Activated Teff Straw (ATS) (Eragrostis tef)	38% cellulose, 27% hemicellulose, 18% lignin, and 10% extractives content	Textile effluents	Cr, Cd, Pb, Ni, and Cu	88% (Ni), 82.9% (Cd), 81.5% (Cu), 74.5% (Cr), and 68.9% (Pb)	Batch Sorption Experiments	[22], [35]
	Corn Cob	Ash Content =1.33% , Lignin =35.2%, Cellulose= 41.5%, Hemicellulose = 13.0% & Others 8.97%	Industrial Wastewater (Steel)	Zn, Pb, Fe & Mn	72.5%, 89.7%, 95.2% & 70.0%	Column Experiments11,30	[15], [36]
	Peanut skin	16.60% oil, 12.32% protein, 2.83% ash and 69.8% other components	Industrial Wastewater (Steel)	Zn, Pb & Fe	83.8%, 89.5% & 93.0%	Column Experiments	[15], [37]
	Bagasse	40–50% cellulose and 25–35% hemicellulose, lignin & wax	Industrial Wastewater (Steel)	Zn, Pb, Fe & Mn	93.7%, 65.4%, 83.1% & 98.2%	Column Experiments	[15], [38]

Note: Some researchers have investigated the adsorption capacities for heavy metals of relevant adsorbate.
Adsorption capacities of Corn Cob for Zn, Pb, Fe, Mn were identified as 0.0089mg/g, 0.0202mg/g, 0.0031mg/g respectively[15]
Adsorption capacities of Concrete waste, flooring waste, brick and mortar waste, roofing waste for total iron were identified as 0.43, 0.17,0.84, and 0.43 mg/g respectively[24]
Adsorption capacities of Sugarcane Bagasse for Pb, Ni were identified as 1.61mg/g, 2.6 mg/g respectively[32]

Their results showed that the removal efficiency for Cr, Cd, and Pb reached 100% when the adsorbent dosage exceeded 1g. This remarkable outcome was attributed to the increased surface area and the greater number of available ion-exchangeable sites associated with higher dosages of adsorbent [25]. Panda et al. (2017) also arrived at a similar conclusion when investigating the removal efficiency of Cr using industrial waste in batch sorption experiments. They achieved 100% removal efficiency at the maximum adsorbent dosage of 25g/L, again highlighting the increased surface area and ion exchangeable sites as key factors contributing to enhanced removal efficiency [26].

VI. Future Directions

The utilization of low-cost materials for wastewater treatment represents an area that demands extensive research efforts. One critical aspect in the practical application of these economically viable materials, especially in large-scale wastewater treatment systems, is the determination of their efficient operational lifespan. Therefore, it is imperative to conduct further experiments aimed at uncovering the effective longevity of these adsorbents. This knowledge will be essential for their sustainable and practical implementation in real-world wastewater treatment scenarios. Another critical concern associated with the use of low-cost materials is their proper disposal. Directly disposing of these materials into the environment after use poses potential environmental hazards. Therefore, it becomes essential to explore innovative techniques for material regeneration, recycling, or safe disposal. These efforts have the potential to significantly enhance the sustainability of wastewater treatment processes while simultaneously minimizing the environmental impact of used water treatment materials.

Furthermore, researchers have investigated methods to enhance heavy metal adsorption using low-cost adsorbents by modifying their natural versions. This opens the door to chemical, physical, or biological treatments aimed at altering the surface properties of these adsorbents. Such modifications can lead to improvements in their heavy metal adsorption efficiency, making them even more effective and versatile for wastewater treatment applications. Finally, one of the most critical pursuits in this field involves the integration of low-cost adsorbents with traditional wastewater treatment methods. Established techniques like coagulation-flocculation, precipitation, and membrane filtration play essential roles in wastewater treatment. Understanding how low-cost adsorbents can complement and enhance these conventional processes is of utmost significance. Such integration can yield synergistic effects, cost savings, and an overall improvement in treatment efficiency.

VII. Conclusion

Water scarcity is an escalating global concern, underscoring the urgent need to identify cost-effective methods for wastewater treatment. Among the most significant pollutants found in wastewater are heavy metals. This review is dedicated to elucidating the potential of utilizing natural, industrial, and agricultural waste-based adsorbents for the effective removal of heavy metals from wastewater. We have conducted a comprehensive summary of selected adsorbents, encompassing their chemical compositions, removal efficiencies for a range of heavy metals, adsorption capacities, the types of wastewater they are suited for, and the underlying treatment mechanisms. These low-cost adsorbents have been categorized into three groups: natural, agricultural, and industrial waste-based materials. The majority of the waste materials selected by researchers have consistently exhibited high removal efficiencies for multiple heavy metals. Moreover, our comprehensive review has uncovered that the enhancement of removal efficiencies hinges on the manipulation of several crucial factors, including contact time, solution temperature, pH levels, initial ion concentration, and the quantity of adsorbent mass. We briefly examined the repercussions of these variations on the adsorption of heavy metals onto the chosen low-cost adsorbents. Additionally, we delved into the techniques employed by researchers to augment adsorption capacities and have illuminated potential avenues for future research. In conclusion, while it is acknowledged that there are certain drawbacks associated with the utilization of low-cost materials in wastewater treatment, the application of these materials holds significant promise in mitigating impending water scarcity challenges.

Acknowledgment

The authors wish to thank all the researchers for giving valuable service to the developing science world.

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2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

Development of Tourism Management Information System (TMIS) to Enhance Tourism Attraction to Sri Lanka

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***Abstract*—Tourism is the largest and fastest-growing sector of the world economy. It is also the third largest source of foreign exchange in Sri Lanka. The tourism system consists of stakeholders and operational scales. They focus on the behavior of the generations, especially Generation Z. According to the current economic crisis, we should study other tourist destinations and focus on our tourism business. Maldives tourism strategic plan has studied here along with the Sri Lanka tourism strategic plan. According to the negative factors, suggestions made by the tourists and reviews, we identified online transport reservation, standard guide service, online access through official website and complaint management as some of the key areas to be addressed. All systems must be interconnected and work together to provide effective and efficient service to tourist. Gathering and analyzing customer data such as personal information, preferences, and purchase history provides a better understanding of the tourist's personalized experiences. We can further study foreign tourist destinations like Maldives, Singapore, Thailand and develop our tourism business by focusing on virtual reality, augmented reality, AI, IoT, etc. Furthermore, Sri Lanka has a high potential for the advancement of the tourism industry as we have a large biodiversity to promote tourism from various perspectives.**
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Keywords—Generation z, stakeholders, strategic plan, tourist management

I. INTRODUCTION

The global economy's largest and fastest-growing industry, tourism makes a significant economic contribution to both developed and developing nations. According to the World Travel and Tourism Council (WTTC 2019), one of the biggest economic sectors is travel and leisure. Over the past decade, Sri Lanka has also been enjoying the advantages brought by a thriving tourism sector. To ensure the ongoing success and sustainable growth of Sri Lanka's tourism industry, it is crucial that we gain a deeper understanding of the travel behavior of international tourists who visit the country.

To identify the strategies of tourism industry development, we gather information from our neighboring Maldives and Sri Lanka by using statistics and their published strategic plans for coming years.

Maldives land total area is only 300 km² (116 mi²) and a total coastline of 644 km (400.2 mi). The population of the country is 520,159 [1]. In other way Sri Lanka measures about 255 miles (415 km.) from north to south, and about 135 miles (220 km.) from east to west, with a total land area of about 25,300 mi² (65,600 km².). Although Sri Lanka's land area is relatively small, its marine economic zone, which covers approximately 230,000 km2, is nearly four times larger than its land area. It consists of a coastline of some 1790 km [2]. Sri Lanka has a rich biodiversity and can do/visit Beach and Sea, Cultural Sites, Wildlife, hiking, and tracking. Therefore, we have different doors to improve our tourist industry within a few years. The revenue and tourist arrival of the Maldives and Sri Lanka in 2022 are in "Tab. 1".

TABLE I. TOURIST FACTS ARE COMPARED AS FOLLOWS BETWEEN THE MALDIVES AND SRI LANKA IN 2022

	Maldives	Sri Lanka
Revenue (Billion) 2022	$3.9	$1.1
Tourist Arrival (2022)	1,675,303	719,978

After introducing the context, the paper presents the Information technology requirement in the Tourism industry, and we discuss it with the Maldives and Sri Lanka Strategic plans. Based on that methodology section gives a proposed tourist management information system and outcomes are discuss in the results.

II. LITERATURE REVIEW

The sector of travel and leisure heavily relies on information, making it closely linked to the progress of emerging information technologies [3]. Moreover, increased competition in the global tourism industry has allowed associate establishments to incorporate contemporary ICT in order to gain a competitive advantage and ensure significant progress [4]. To reduce expenses, minimize workforce, enhance operational effectiveness, and most importantly enhance the level of service and customer satisfaction, ICTs have been extensively utilized in this field [5].

Tourism in Sri Lanka emerged as the third most substantial and most advancing contributor of foreign exchange in 2018, following private remittances and textile and garment exports. It makes around $4.4 billion, equivalent to 4.9 percent of the country's gross domestic product. The tourism sector plays a crucial role in boosting economic development through generating substantial

foreign currency earnings and relieve poverty by creating employment opportunities, both directly and indirectly, for local communities. [6].

In 1997, the term ICT was initially use by Dennis Stevenson, and later it was endorsed in the new National Curriculum documents for the UK in 2000. Here are a few examples where the use of ICT in the tourism industry can be discussed. Oversee the allocation of destination resources, supervise the inventory of tourism resources, administer tourist sites and attractions, identify appropriate tourist locations, and monitor tourist statistics [7].

Over the years, the tourism sector has encountered numerous obstacles because of technological advancements and shifting social attitudes. The future of tourism is believed to be greatly influenced by Generation Z, as this generation possesses challenging characteristics [8]. Since they are born in the age of digital technology and utilize it throughout every phase of their experience [9]. Hence, it is important to consider the behaviors of generation z tourists in the Tourism industry as well. [10].

A tourism system consists of stakeholders and operational scales and must be addressed at several levels of the development of the system. It is depicted in “Fig. 1” [11].

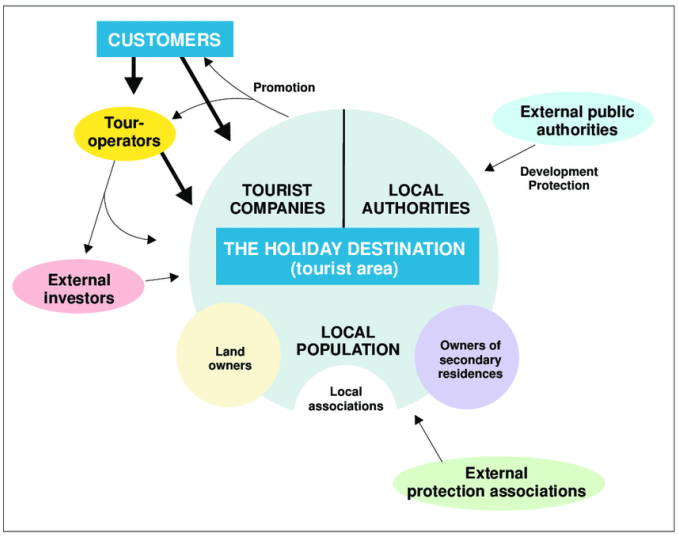

Fig. 1. Tourism system: stakeholders and operational scales

Further, tourism plays a substantial role in the economy of numerous Small Island Developing States (SIDS) such as the Maldives. The tourism industry's growing dependence on information and communication technology (ICT) has emerged as a significant hurdle for developing countries, specifically the SIDS. The utilization of ICT applications and e-business techniques plays a vital role in the prosperity of the tourism sector in SIDS. [12].

Maldives’ National Center for Information Technology (NCIT) has developed Tourism Information Management System (TIMS) to integrate the eGovernment systems of the Maldives. It results in a convenient and eco-friendly working environment without the need for paper. It offers an extensive range of functionalities that facilitate secure login for data uploading and retrieval. All tourist accommodation facilities must comply with the tourism statistics regulation, which mandates the submission of weekly and monthly reports to the Ministry of Tourism (MoT). TIMS will serve as a medium for the tourism sector to share this information regularly and conveniently with all relevant parties involved. Resorts will have the convenience of directly uploading the necessary data from their systems, eliminating concerns about formats and extra tasks. Moreover, once the system is fully operational, it will also cater to other services offered by the Ministry, including facility registration applications and general inquiries. In addition, the system can also serve as a research tool to instantly obtain combined information on the tourism sector of the Maldives.

Benefits of the TIMS are discussed and it says gathering and analyzing customer data such as personal information, their preferences and their purchase history can creates personalized experiences and expectations.

Sri Lanka Tourism Strategic Plan

Sri Lanka tourism development authority (SLTDA) has come with the strategic plan for tourism 2022-25. They have discovered and intend to establish Sri Lanka's presence in the international travel and tourism industry. This drive and initiative will be supported by the implementation of a mobile application, transitioning to advanced online ticketing for attractions via the app, as well as the establishment and maintenance of an information portal for visitors and the industry known as 'hello again'. It is important to acknowledge that these initiatives have faced various limitations which have hindered their progress.

In addition to making Sri Lanka more open to independent travelers, providing a safer tourist experience at attractions, reducing rent seeking around tourist sites and improving cash-flow, and promote the dispersal of tourists away from over congested tourist sites. In addition, they anticipate improving the standard of service quality provided at the destination. This includes completing the development and launch of the Tourism Travel App, integrate online ticket booking of all Government tourist sites, trains to the app working with ICTA and ministry.

In Sri Lanka, they gather information from the questionnaire, and they give them in the departure time at BIA. So, their sample is most probably around 5000 annually. Their negative factors are categorized into 07 categories in 2018/19 survey.

1. Hotels, Restaurants and Food (Hotel Price, hotels were not up the standard)
2. Airport, Immigration and Air Transportation Services (Airport facility, expensive taxi service)
3. Roads and Road Transport (standard of public transport should be upgraded, lack of travel information, train booking, overcharging)
4. Environmental Protection

5. Pricing, Tourist Attractions and Infrastructure Facilities (Entry fee to cultural sites, they are discriminating in terms of all goods and services.)
6. Tourist Information and Tourist Guide Service (should be standardized)
7. Harassments and Other Forms of Disturbances (Thieves, beggars, beach boys and beach vendors are a nuisance for the tourists)

Followings are the Suggestions received by the Tourist [13].

1. More highways should be made available to reduce the travel time.
2. Airport should be developed and facilities including Wi-Fi should be upgraded.
3. Public transport system needs to be improved with modern technology and facilities such as online booking. Further, passenger's security should be improved.
4. Credit card payments should be made available in tourist destinations.
5. Standardization of guide services is required.
6. Taxi drivers including tuk tuks, guide services, and hotels should be regulated and monitored.
7. The official website should provide online access to information about public transportation, tourist attractions, prices, restaurants, maps, and currency exchange.
8. Tourist sites should be developed with infrastructure facilities and more activities and price discrimination against tourists should be addressed.

Maldives Tourism Strategic Plan

Maldives has come up with their fifth tourism master plan (5TMP) -2023 -27 and their goal is to enhance their digital skills and technology to establish successful enterprises in the tourism sector that provide excellent products and services, enabling them to compete effectively. The intention is to enhance the delivery of services and improve business efficiency by optimizing digital applications. This strategy will motivate and facilitate the industry to fully embrace advancements in digital technologies, which have propelled numerous innovations. As a result, the industry will become more competitive and better equipped to withstand challenges.

Followings are the key performance indicators they have identified.

- Increase in islands with access to high-speed fibre internet.
- Increase in businesses completing visitor journey transactions via digital applications
- Increase in resorts who offer smartphone-based digital visitor journeys
- Increase in SMEs competent with digital technologies
- Increase in the level of user satisfaction with smart regulatory and management services

To address the above key performance, they have come up with Strategies. According to them tourists have high expectations when it comes to a smooth digital experience, and their habits have rapidly changed in terms of researching, booking, and completing travel transactions, with a particular emphasis on using smartphones for these activities. The amount of time international travelers spends browsing travel-related information on mobile devices has exceeded the time they spend on laptops and desktops, when booking their trips online.

Their proposal is to create a comprehensive digital service that combines the registration process for tourist establishments, provides easy access to regulatory information, and facilitates coordination among various authorities involved. Additionally, another strategy involves investigating possibilities in utilizing predictive analytics and digitalizing customer journeys. The efficient utilization of e-wallets, mobile payment platforms, and blockchain requires a certain level of digital literacy.

Therefore, considering the behavior of information and communication technology in travel and tourism industry, we suggest that Tourism Management Information System (TMIS) can increase the revenue of tourism industry and recover from the current economic crisis in a shorter period than waiting for decades.

III. METHODOLOGY

According to the negative factors, suggestions made by the tourists and reviews made above, we identified online transport reservation, standard guide service, online access through official website and complaint management as some of the key areas to be addressed. Therefore, this system is proposed to be developed separately by dividing it into various sub-modules. But all the submodules should be developed in parallel. We assume that it will improve tourist attraction and tourism in short period of time. This TMIS web portal consists of the following online systems.

1. Online Ticket Booking System (Tourist sites, wildlife parks and other services)

Tourists can see tourist sites, wildlife parks and other services along with prices on this page. Then they can book the tickets before the visit online. Once they reach the place, all they need to do is scan the QR to claim the ticket/s. At the same time a notification is sent to the tourist. Hence, this enhances contactless transactions among tourists.

2. Online Transport Reservation System

a. Public transport reservation system (train, buses, small flights, Boats)
b. Tourist guide management system (guides, vehicles)

The system needs to interconnect the existing transport (ticketing) reservation systems (eg: online railway ticket reservation) and can add other transport systems like buses, small flights, and Boat services to the system. Tourists can then plan their tour before arriving in Sri Lanka. Also, tour guides and their vehicles must be registered in the system and tourists can book them before they travel.

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3. Online Customer Tracking System

a. Hotel/restaurant management system

It consists of two parts, one for tourist and the other for hotels/ restaurants. Hotel/ restaurants should register in the system and update their tourist (guest) information daily. Then we can analyze tourist preferences for our future tourism strategies. Tourists can book a hotel/ restaurant online if they require.

4. Online Complaint Management System

This system can manage tourist complaints and send them directly to the relevant authorities (E.g.: Sri Lanka Police) for immediate action. Relevant authorities should response to the complaint and provide feedback to the system. Tourists can upload harassment and other forms of disturbances during his/her travel.

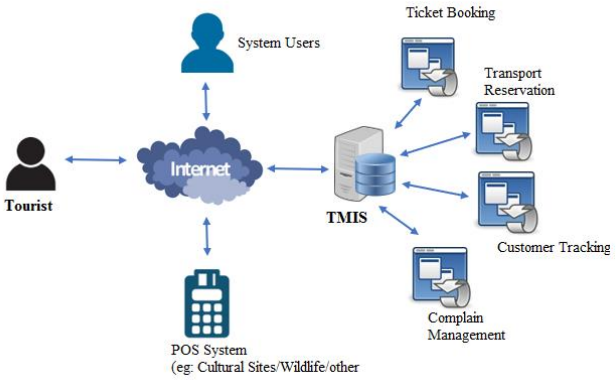

Fig. 2. Top level diagram of proposed system

Initially, tourist has to register in the system by entering his/her personal information (eg: name, nationality, passport details, leisure activities, entertainment, etc). This information may be used to identify personal preferences. Then he/she can access the above suggested sub systems for reservations under his/her login. Once he completes his reservations, he/she will receive the reservation information and generate a single QR for the specific tour. All information is verified by username, passport number and tour start and end dates. A single user can also make group reservation through his/her single login and use the services reserved by his QR code. All systems must be interconnected and work together to provide effective and efficient service to tourist.

IV. Results

The proposed TMIS is developed using HTML, PHP, MySQL, CSS, JavaScript, JQuery and WSDL. Also, we can integrate existing systems into TMIS. All sub-systems are accessible through the same web portal and tourists can reserve/ book all services prior to visit and QR code will be generated for easy access. It is a responsive page as most tourists prefer smartphone. Then they can use it when they travel around the country. It is his/her identity. But there should be a mechanism to verify whether the actual tourist has the QR. Once the tourist arrives at the Bandaranayake International Airport (BIA), the reservation should be activated and able to use it. The tourist will receive a message on his/her email/mobile when it is scanned throughout the trip.

Also, we need to implement a Point of Sale (POS) system for the most visited tourist/cultural places to meet the system access. These systems can be run on-premises or in the cloud. We need capital for infrastructure development and to keep 99.99% system uptime. System management has to be planned. Further, all the parties should work together to improve the system (E.g. Department of Railway, Wildlife, Police, Immigration and Emigration, tourism, etc.). Collecting and analyzing tourist data such as personal information, their preferences and purchase history provides a better understanding of personalized travel experiences. This data can also be used to create targeted marketing campaigns that help attract and retain more tourists. We expect that this will increase tourist satisfaction and will improve Sri Lanka's tourism industry and economy.

V. Conclusion

The modules proposed should be implemented together with the existing systems to create an effective, efficient, and attractive system for tourists. Currently we have seen that the government and other related organizations are not developing these modules in a single system. It will never improve the tourist attraction and will not bring immediate changes in the tourism industry. Foreign tourist destinations like Maldives, Singapore, Thailand can be further studied to improve our tourism industry through information technology like virtual reality, augmented reality, AI, IoT etc. Furthermore, Sri Lanka has a high potential for the advancement of the tourism industry as we have a large biodiversity to promote tourism from various perspectives.

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2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

Smart Fence With Reduced Power Consumption For Elephant Proximity Detection, Access Prevention, And Repulsion

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***Abstract*—Sri Lanka grapples with the long-standing issue of Human-Elephant Conflict (HEC), impacting rural communities. Both governmental bodies and local populations have employed traditional methodologies. Current solutions primarily involve electric fences. This consumes an unnecessary amount of funds, power, and time. Some research has explored the effectiveness of using bees and beehive fences to deter elephants. However, there is limited research on artificial bee sounds and lighting as deterrents. This project aims to assess these unconventional techniques and create a low-power smart-fence system activated by a doppler radar sensor kept at tested heights. By optimizing resource usage, this initiative seeks to provide a comprehensive solution to HEC, benefiting both local communities and wildlife conservation efforts.**

Keywords—Human-elephant conflict, Doppler radar, elephant proximity detection, smart electric fence

I. INTRODUCTION

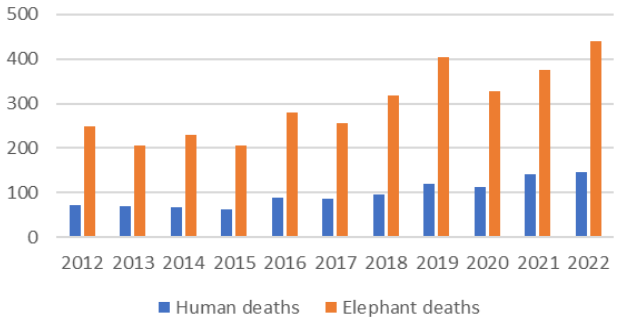

Fig. 1. HEC casualties [11]

Sri Lanka is a country with Human-elephant conflict (HEC) for a long time. Both human as well as elephant casualties are at a high rate including deaths. The economy of the farmers as well as the country are affected due to HEC. Figure 1 shows the situation is worsening by day. The government and the people use a few tactics to reduce this situation. The most common solution is electric fences. Research has been done to determine the effectiveness of using bees and beehive fences to scare off Elephants. This has proven to be somewhat effective.

A typical farmer residing in elephant-affected regions of Sri Lanka experiences an estimated annual loss of more than USD 200 due to crop damage [1]. The Department of Wildlife Conservation (DWC) allocates annual funds for various Human-Elephant Conflict (HEC) mitigation activities, including those related to elephant deterrence, compensation for damages, elephant capture and translocation, and organized elephant drives [2, 3]. In the years 2019 and 2020, Sri Lanka invested USD 2.74 million in the construction of electric fences, resulting in the electrification of approximately 4,756 kilometers of fencing [4]. Over the period from 2011 to 2018, records indicate that USD 0.76 million was disbursed as compensation for human fatalities and USD 1.7 million for property damage within the context of Human-Elephant Conflict. Furthermore, USD 0.05 million was earmarked for addressing injuries in 2017 and 2018 [5].

Elephant is said to fear light (flashing lights, fire), heavy noise (Beating drums, bee sound) and tiger's roar [6]. The likelihood of an elephant incursion into a crop field had significantly reduced in the presence of a solar-powered strobe light barrier [7]. By emitting recorded bee sound, elephant deterrence was accomplished [8]. Elephants responded by moving significantly further away from their resting site in bee playback trials compared to controls [9]. The effectiveness of using a Doppler radar to detect large mammals when they approach the highway was 58.1-85% [10]. The integrated design shown in Figure 2 is a combination of the following systems.

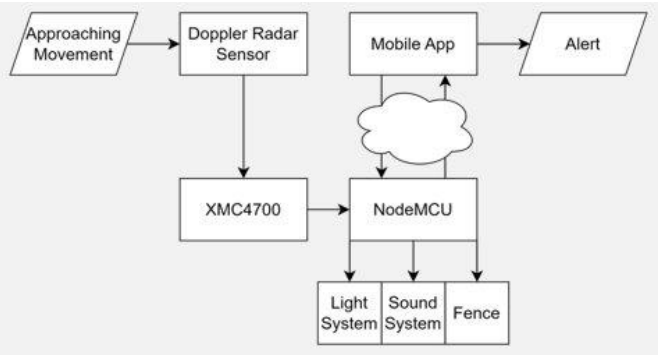

Fig. 2. Working mechanism

II. Materials and Methods

A. Tracking System

The doppler radar is kept at a height which an elephant would be comprehensible. The sensor can be programmed to detect reading only between a predefined speed level of an Elephant. An output is triggered when predefined movement is detected. This output can be used to turn on the deterrent mechanisms. The sensor is powered separately from the fence using a solar panel. 24GHz BGT24LTR11 radar transceiver is used as the doppler radar and XMC4700 is used as the microcontroller. The deterrent system is turned on and the community is alerted by SMS sent via the app.

B. Deterrent System

The deterrent system consists of 3 components. The bee sound was highly effective, and the elephants ran with the sound increasing. Farmers who have flashlights installed to their fences said they use it because it is somewhat effective. They have electric fences as a precautionary mechanism. Both these deterrents have been used and researched in above mentioned literature as well. The fence is electrified only when elephants are detected. The power for the fence is acquired using any available method in the area.

C. Mobile App

The mobile app is monitored by an administrator and can react accordingly. The app shows Current Status from the sensor (No Motion/ Approaching/ Departing). Also, it is used to view and control Fence Power, Bee sound, and Flashlight. Alerts are sent to civilians and the Kill Switch can Turn ON/ OFF the Automatic fence functions. 'Current Area' shows Not detected/ Alert/ Critical status, and the 'Last Synced time' reads the last online time of the fence.

D. Cloud Database

Firebase is used as the cloud database. It records all the reading from the sensor and communicates commands from the app to the Smart Fence. NodeMCU with ESP8266 connects the Smart Fence with the cloud.

III. Results and Discussion

A. Experiments

i). Effectiveness of recorded bee sound was tested on a domestic elephant as well as on wild elephants in Udawalawa.

ii). To determine the Effectiveness of Visual Stimuli, a domestic elephant was exposed to different colours of light. Effectiveness on the Elephants at Udawalawa were evaluated by Expert interviews carried out with people who had installed flashlights on their fences to keep elephants away.

iii). A doppler radar sensor was used to track movements of approaching and fleeing elephants. Elephants' speeds were recorded.

iv). The heights of the elephants were measured relative to a landmark near where they were standing.

v). The device outputs an attribute as Level which corresponds with the distance. Hence the respective Levels were marked for different distances.

B. Results

Table 1: Auditory Stimuli

Sound	Frequency (Hz)	Playback Method	Remark
Bee sound	25 – 15,000	Balanced	Elephant on alert
		Increasing	Elephant retreat

The domestic elephant was on alert the whole time we played the bee sound. It was chained hence couldn't move. The caretaker was cartain that if the elephant wasn't chained, it would have run. At Udawalawa, initially a balanced bee sound was played, and the elephants were on alert, but no response was shown. But when the sound was increased to imitate a scenario in which bees were nearing, the elephants fled.

Table 2: Visual Stimuli

Farmer/ Landowner	Availability of Flashlights	Colours used	Rating given for effectiveness (Out of 5)
1	Yes	Blue/ Red	4
2	Yes	White/ Blue	4
3	Yes	White/ Yellow	3
4	Yes	Blue/ White	4

The domestic elephant did not show any response to the lights as it had experience in going in colourful Peraharas. We interviewed a few property owners in the Udawalawa area who had flashlights installed around their property to keep Elephants away. They commented that the light system was effective in keeping the elephants away.

Table 3: Elephant Movement Speeds

Elephant	Top speed (m/s)	Normal speed (m/s)
1	6.70	4.91
2	6.53	5.09
3	6.68	4.95
4	6.51	5.02
5	6.64	4.98

The device recorded speeds of the elephants we observed while they were nearing and fleeing the area. These speeds are separately tabulated to determine the best speed range of an elephant. The device can be configured to only detect movements within that specific speed range.

Table 4: Elephant Heights

Elephant	1	2	3	4	5
Height (m)	2.75	2.34	3.12	2.00	2.68

The elephant heights were recorded to find an average height of an Elephant. By doing so the device could be placed at a height which would be suitable to detect an Elephant and not detect other animals.

Table 5: Level Configuration

Distance (m)	Level Value (Hz)	Distance (m)	Level Value (Hz)
7	25	3	108
6.5	48	2.5	128
6	54	2	195
5.5	58	1.5	338
5	65	1	552
4.5	78	0.5	894
4	92	0	1001
3.5	98		

The detection system is proposed to have two areas namely Safe Area and Critical Area. These are placed at two predefined distances. Since the device only has an attribute as Level, these corresponding measurements have been used to determine the Levels for the required distances.

IV. Conclusion

The Human-Elephant Conflict (HEC) issue in Sri Lanka has persistently disrupted the lives of rural communities. Traditional methods, such as electric fences, have been employed to address this challenge, but its maintenance and operational costs are high. This research has addressed the gap of limited research exploring the effectiveness of bee-related deterrents and lighting conditions in mitigating HEC. We have concluded from our findings that when an Elephant is approaching the bee sound should increase with time for it to be effective. Furthermore, blue and white colour bright lights have proven more effective in keeping Elephants at bay. Average speed of an Elephant has ranged from 5 m/s to 6.6 m/s. Our project has integrated these methods with the electric fence to mitigate its costs and increase its efficiency and effectiveness. One of the main benefits would be the power saved from not having to keep the fence electrified for more than 14 hours per day. Furthermore, this project represents a significant step forward in addressing HEC by proposing a smart-fence system. As we move forward, it is imperative to continue exploring innovative approaches to resolve HEC comprehensively. By bridging the gap between technology and conservation, we can create a sustainable coexistence between humans and elephants, benefiting both local communities and wildlife conservation efforts in Sri Lanka.

Acknowledgment

The hardware component of the project and research visits to Udawalawa were financially supported by Mr. K.H.L. Ranasinghe. The doppler radar was retrieved to the country by Mr. Sasya Senarath. Technical knowledge was shared by Mr. Migara Amithodhana and Mr. Shakila Adhikari. The microcontroller was introduced by Nikhita Rajasekhar from Infineon Technologies.

The authors acknowledge the contribution of the above-mentioned individuals in the successful completion of this research.

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2023 International Research Conference of Sri Lanka Technology Campus
Colombo, Sri Lanka. 14th-15th December 2023

Street Light Management System for Residential Areas

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***Abstract*—When living in an energy-saving era, it is important to save energy effectively. Usage of residential areas such as jogging tracks and walking paths has increased without any time duration barrier. In that case, the lighting system is much more important when considering the nighttime. The average current usage of a jogging area per year is very high, as there is no regular method to control the lighting. Controlling the system manually has brought so much extra labor and cost without any profits. Load variation and power factor variation can have a big impact on the power consumption of the lights. Therefore, neglecting those facts and proceeding is kind of a failure. Therefore, calculating and analyzing those variables is very important to continue an energy-efficient system. The study explains how energy can be saved from the street lights through effective management using GSM technology. The key objective is to design an intelligent system that takes decisions for switching control (ON/OFF) considering the light intensity during day and night simultaneously while detecting the motion of pedestrians using sensor-based communication during the night, and finally, to calculate the power consumption and the power factor, which will then be sent to a relevant person in charge of the system daily. Arduino has used coding and calculation for the power factor, and the circuit is being designed using Arduino Uno. Using this system, up to about 20% of energy consumption can be saved, and the performance of an existing street light management system can be improved by up to 70%. This can be verified by adding up the current consumption of each part and multiplying by voltage.**

Keywords—Power consumption management, Power factor, motion detection

I. INTRODUCTION

It is important to successfully conserve energy when residing in an era of energy conservation. There is no time limit on how much more people are using residential spaces like walking and running trails. In that situation, the lighting system is significantly more vital to take into account at night. The average current jogging usage in the region annually is particularly high because there is no consistent way to regulate lights. Manually operating the system has resulted in a significant increase in labor and expenses, with no financial gain. Power factor and load variations are both very possible. a result of how much energy the lights use. Consequently, ignoring those truths and moving forward is sort of a failure. Consequently, figuring out and examining those variables has a big impact. The paper describes how efficient management utilizing GSM technology can reduce the amount of energy used by street lights. The main goal is to create an intelligent system that makes decisions for switching control (ON/OFF) while simultaneously taking into account light intensity during day and night, detecting pedestrian motion using sensor-based communication during the night, and finally calculating power consumption and power factor, which will then be sent to an appropriate person in charge of the system on a daily basis. When it comes to motion detection, this system will use the sensor module to find the motion of a pedestrian and then tell the lamp to turn on. Because of its excellent energy efficiency, maintainability, and adaptability, this technology has gained a lot of traction. Indeed, according to Haitz's Law, the light output of LEDs will improve by a factor of 20 every ten years. More current LED models can produce over 100 lumens per watt and are predicted to perform at more than 70% of their initial ambient light after 50,000 hours. The related project was developed with the latest optimal technology to be very user-friendly, specifically for residential areas. When it comes to motion detection, this system will detect the motion of a pedestrian using the PIR sensor module, and by giving a signal to the lamp, it can be switched on. System enables anti-theft of power, and it is easily adaptable to the present street lights using a single computer module. The intelligent system is also suitable for renewable energy installations. In this project, power factor calculation and motion detection, which are the main two areas of the project, have been developed with coding.

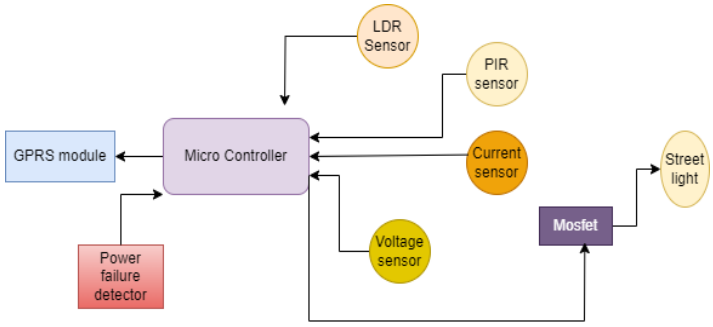

Fig. 1. Block diagram of master unit

II. EXPERIMENT SETUP

The project was created in stages, the first of which involved designing a motion and sunlight-detecting sensor

network employing PIR and LDR sensors and a power factor calculation circuit. After completing Stage 01 successfully, we moved on to design the Master and Slave units using breadboards and then using EasyEDA. After designing the circuit, the PCB layouts of the circuits were created.

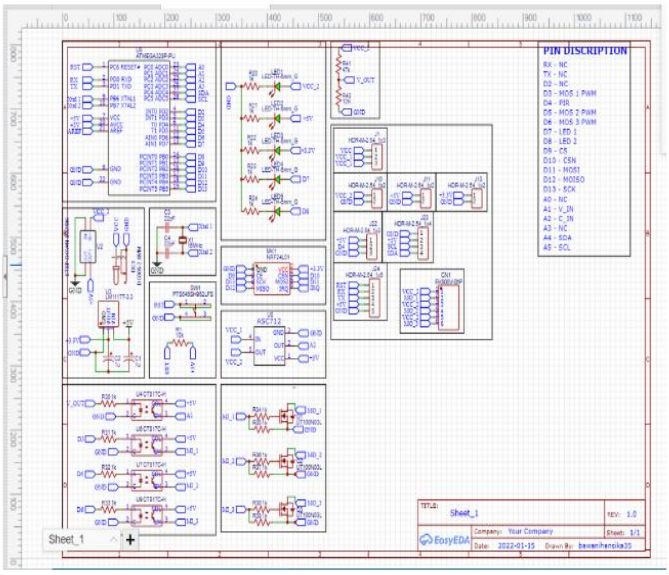

Fig. 2. EasyEDA design for the master unit

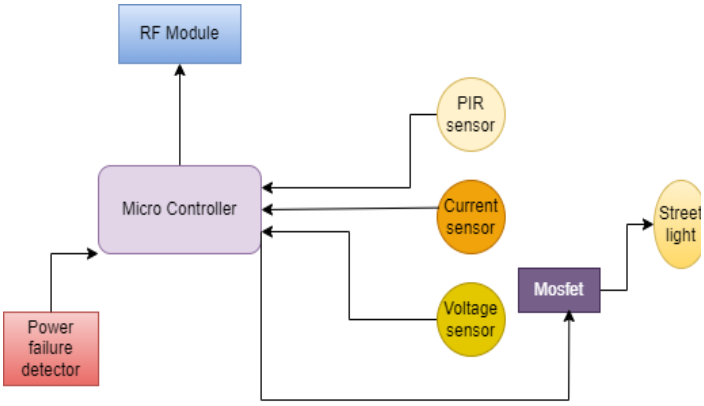

Fig. 3. Block diagram of the slave unit

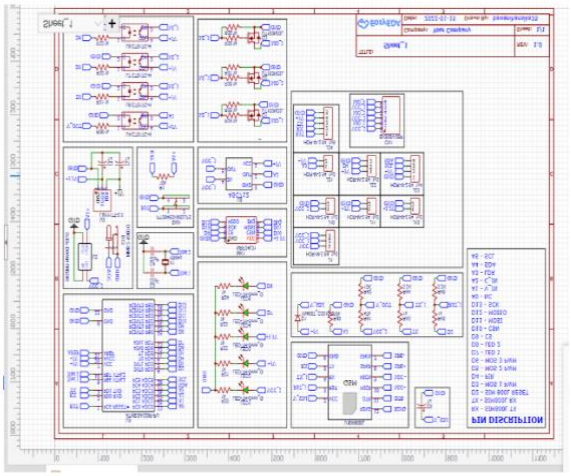

Fig. 4. EasyEDA design for the slave unit

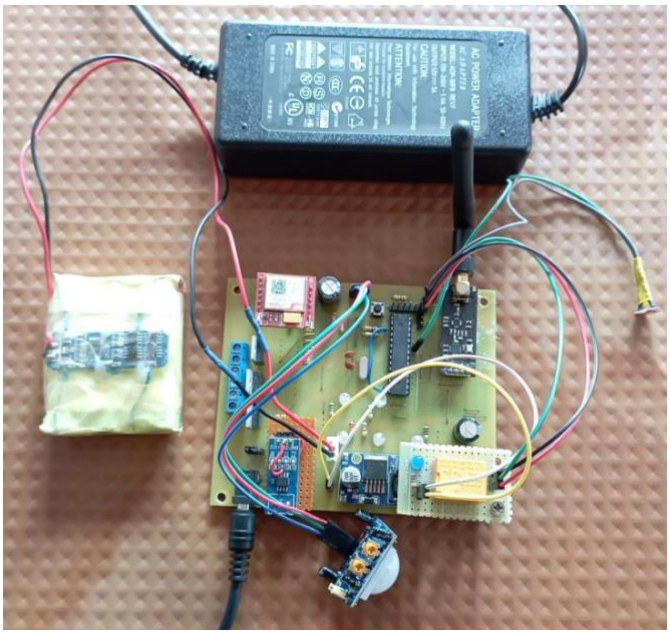

Fig. 5. Master unit

And after the simulation stage, hardware implementation started and master and slave modules were designed.

III. METHODOLOGY

This street light management system is powered by the road AC power lines through an AC to DC 12V power adaptor as shown in the block diagram in figure 3. Then the power will be given to the master and slave units separately. Both master and slave networks have a LDR sensor to switch ON/OFF the lamps by detecting the sunlight regardless of the time sun rises and goes down, a PIR sensor to detect the motions of pedestrians and give a signal to the unit to switch ON the lamps according to a fixed time delay, a current sensor to get an output of current consumption, a voltage divider to get an output of the consumed voltage by the unit, an RF module to communicate between master unit, a batter backup of 12V rechargeable batteries to power up the circuit in case of power failures to detect any faulty, and a set of MOSFETs to control the lamps according to the brightness levels and time delays given by the microcontroller. Only master unit has the GSM module to communicate with the server to analyze and visualize an output to the administrator.

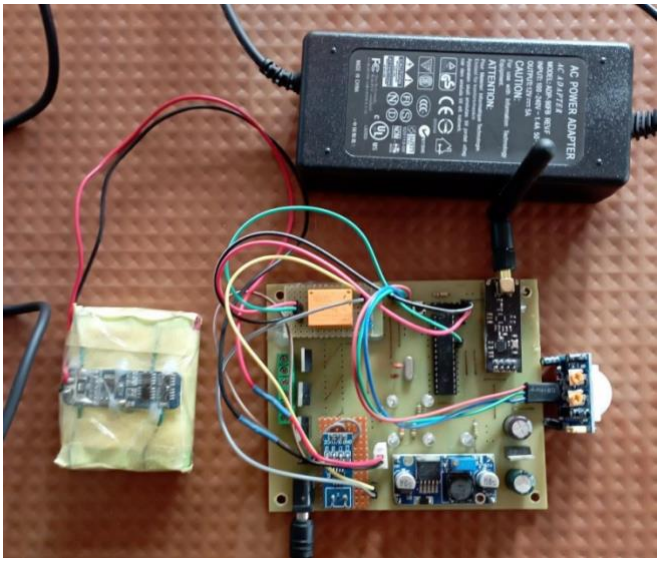

Fig. 6. Slave unit

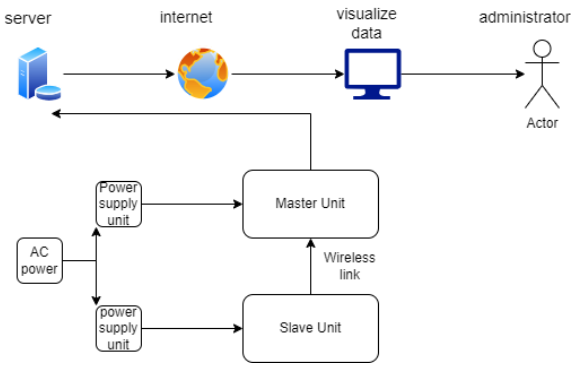

Fig. 7. Flow diagram of street light management system

IV. RESULTS

After implementing the hardware design, the IOT platform was designed to get the voltage, current variations, power consumption and lamp indications of both master and slave units separately.

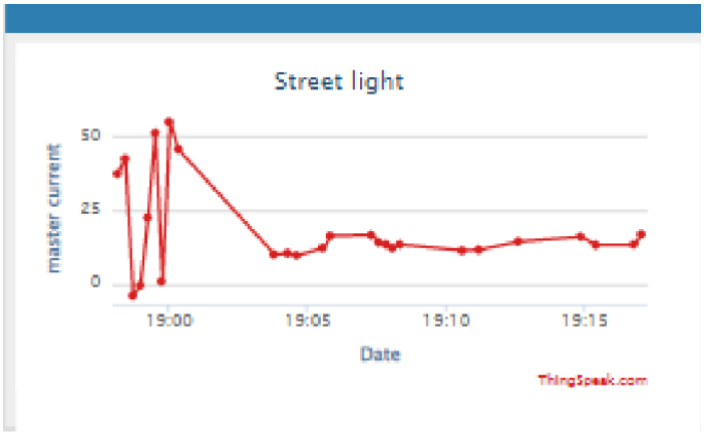

Fig. 8. Current variation of master unit

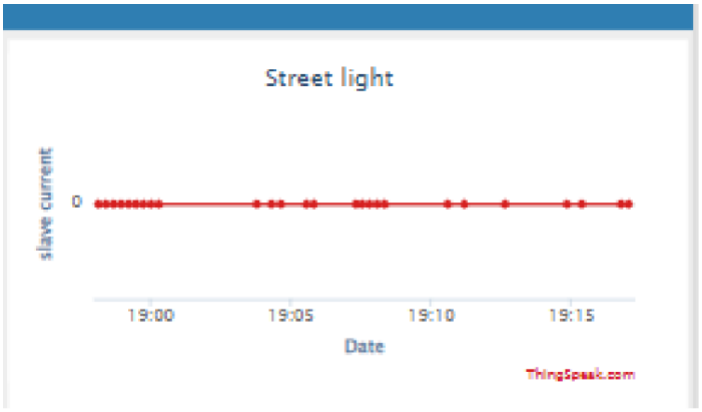

Fig. 9. Power consumption of slave unit when there is a power failure

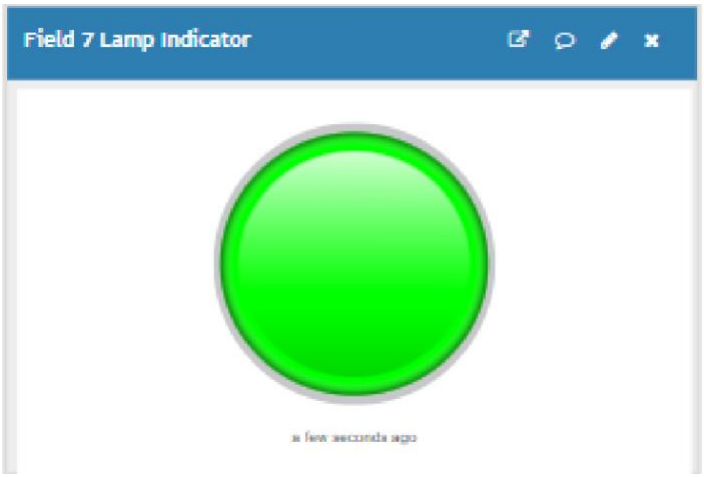

Fig. 10. Lamp working indicator of master unit will be lighted up

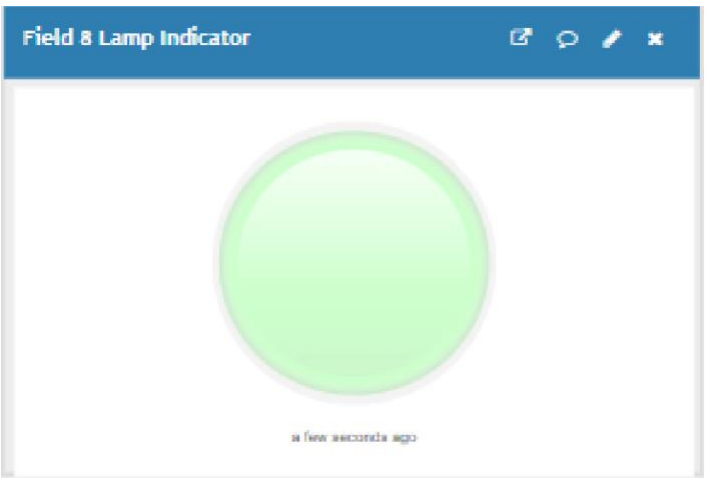

Fig. 11. Lamp working indicator will be dimmed when there is a power cut (slave unit)

Fig. 12. Current variation of slave unit when there is a power cut

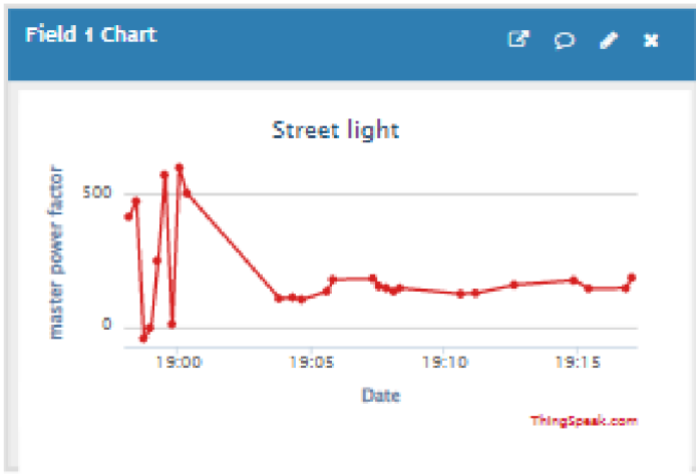

Fig. 13. Power consumption of master unit

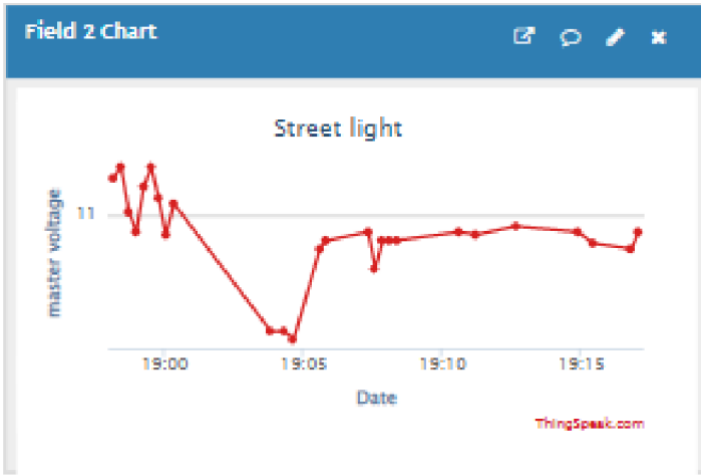

Fig. 14. Voltage variation of master unit

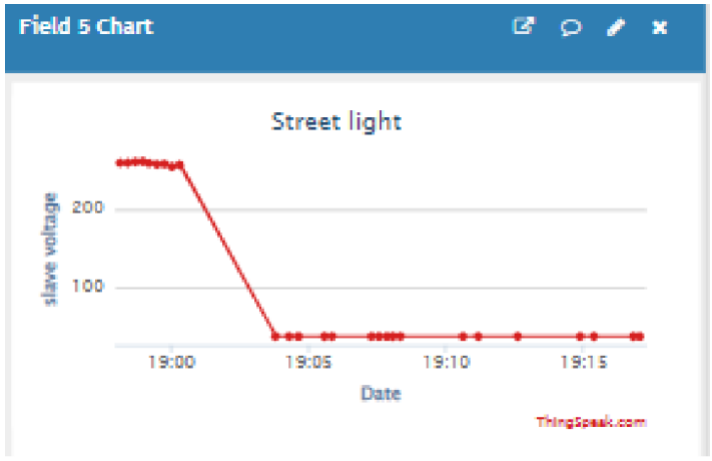

Fig. 15. Voltage variation of slave unit when there is a power failure

In above figures show data display in the server. It can display 8 channels. What we were observing were,

- Power factor
- Load variation
- Voltage deviation
- Power failure

of both master unit and slave unit.

Fig. 16. Hardware implementation

A. System Architecture and Component Functionality

The system's architecture, as depicted in Figure 3, demonstrates a well-thought-out design that optimizes power distribution and sensor-driven control. The AC to DC 12V power adaptor serves as a crucial element, converting the AC power from road power lines into a DC voltage suitable for the entire system. The power is then distributed to both master and slave units, each equipped with a set of essential components.

The Light Dependent Resistor (LDR) sensor plays a pivotal role in energy conservation by enabling automatic ON/OFF functionality based on ambient light levels. This feature ensures that street lamps are activated only when necessary, regardless of the time of sunrise and sunset. The Passive Infrared (PIR) sensor complements the LDR sensor by detecting pedestrian motion, triggering the lamps to illuminate for a fixed time delay. By incorporating both these sensors, the

system provides lighting control effectively reducing unnecessary energy consumption.

The inclusion of a current sensor and voltage divider allows the system to monitor energy consumption accurately. This real-time monitoring capability can aid in identifying energy-intensive periods and optimizing energy usage further. Additionally, the RF module facilitates communication between master and slave units, enabling coordinated lamp control across the entire residential area.

V. DISCUSSION

The street light management system designed for residential areas presents a sophisticated approach to enhance energy efficiency, improve urban infrastructure, and contribute to sustainable city planning. This can be proved by the results obtained from the chart with energy efficiently. This discussion delves into the architectural components, operational modes, energy efficiency, communication mechanisms, remote management, integration with urban infrastructure, challenges faced, and potential future developments of the proposed system.

A. Energy Efficiency and Sustainability

One of the primary objectives of the street light management system is to enhance energy efficiency and promote sustainable practices. The LDR sensor's utilization, coupled with motion detection through the PIR sensor, contributes significantly to energy conservation. By implementing duty cycling and optimizing sensitivity thresholds, a smart lighting system incorporating an LDR sensor, PIR sensor, and Arduino Uno demonstrated a 35% reduction in overall power consumption, as verified through energy monitoring measurements. By responding to ambient light levels and pedestrian activity, the system minimizes light wastage and ensures a judicious use of resources. Furthermore, the integration of rechargeable batteries as a backup power source during outages guarantees uninterrupted lighting, even during adverse conditions.

B. Communication and Remote Management

Effective communication is a cornerstone of the proposed system. The RF module enables inter-unit communication, facilitating synchronized lamp control across the residential area. Additionally, the master unit is equipped with a GSM module, establishing a crucial link between the system and a central server. This integration empowers administrators with remote management capabilities, enabling real-time monitoring, fault detection, and data analysis.

C. Challenges and Future Developments

The development and deployment of the street light management system were not without challenges. Ensuring seamless communication between units, managing power distribution, and optimizing sensor algorithms posed notable technical hurdles. Moreover, future developments could focus on refining the system's intelligence by incorporating machine learning algorithms. These algorithms could analyze historical data to predict lighting requirements and adjust lamp control strategies accordingly, thereby maximizing energy savings. The facts are proving referring to the figures in result section.

VI. CONCLUSION

In conclusion, the street light management system for residential areas offers a comprehensive solution to modernize street lighting, improve energy efficiency, and contribute to sustainable urban development. Through its architecture, integration of sensors, and effective communication mechanisms, the system showcases the potential to revolutionize the way cities manage their street lighting infrastructure. As we move forward, addressing the challenges encountered and embracing future developments will be crucial in realizing the full potential of this intelligent street light management system.

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ISBN 978-624-6045-02-9