SLTC Research University

ORIS Office of Research and Innovation Services

Faculty of Postgraduate Studies and Research

SLTC-International Research Conference Proceedings

irc | 2024

Technology & Innovation for Growth

Fostering Multidisciplinary Research for Sustainable Advancement

International Research Conference 2024

Conference Proceedings

6th and 7th November 2024

SLTC Main Campus | SLTC Trace Campus

IRC 2024

https://irc.sltc.ac.lk/

Conference Venue

SLTC Main Campus | SLTC Trace Campus

Organized by

Sri Lanka Technology Campus, Sri Lanka

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A Message from the
Vice Chancellor

Dear Esteemed participants and guests,

It is with great pride and enthusiasm that I welcome you to the International Research Conference (IRC) 2024, organized under the theme, "Technology & Innovation for Growth: Building Interdisciplinary Research for Sustainable Development." This theme has a good synergy with SLTC's objectives to be a pioneer of highly advanced research and education for sustainable development. This prestigious annual conference is the fourth consecutive year of IRC to be held at our City Campus at Trace City Expert City, Colombo and our Residential Campus at Padukka. SLTC is an island's largest non-state, research-based, and residential tertiary educational institute that aims to promote interdisciplinary research cooperation. The conference offers students, scholars, researchers, workplace professionals, and policymakers, a unique opportunity to meet and share their knowledge and ideas that can lead to the creation of partnerships that may enhance scientific development and research for the benefiting of Sri Lanka and the world. The conference to be held this year will cover numerous spheres of interest varying from Biomedical Engineering to Sustainable Agriculture and even Social Sciences, where all the perspectives of the thematic innovative processes will be studied and discussed. We are also honored to have internationally acclaimed speakers such as Professor .Gehan Amaratunga, Dr. Ravi Fernando and Professor Matsushima Ken-ichi , who will give speeches that will motivate and challenge the participants and the audience to have a better understanding of the goal of research in creating a sustainable world.

I extend my sincere appreciation to the organizing committee for their dedication and hard work in bringing this significant event to life. To our sponsors, partners, and all participants, thank you for your support and commitment to making IRC 2024 a success. May this conference be an enriching experience for all, fostering new knowledge, meaningful collaborations, and a shared vision for a brighter, more sustainable world.

A Message from the
Dr. Lakshitha Pahalagedara

It is my distinct honor to welcome you to the 4th International Research Conference 2024 (IRC 2024), hosted by SLTC Research University under the theme, *"Technology and Innovation for Growth: Fostering Multidisciplinary Research for Sustainable Advancement."* This conference represents a pivotal platform for fostering knowledge exchange, collaboration, and visionary dialogue among scholars, practitioners, and thought leaders from around the world.

In a rapidly evolving global landscape, the role of research and innovation is paramount. Our focus on multidisciplinary collaboration underscores the belief that today's complex challenges require a confluence of diverse perspectives, skills, and expertise. Through this gathering, we aim to push the boundaries of conventional thought and inspire new directions in sustainable development, all driven by the transformative power of technology.

We extend our gratitude to all the researchers, industry experts, and participants contributing to this conference. Your insights and dedication are integral to advancing our collective goals. Together, let us explore pathways to a more sustainable and innovative future.

A Message from the
General Co-Chair

The International Research Conference (IRC) is one of the most important annual events for the SLTC Research University. The IRC highlights the research findings of undergraduates, postgraduates, and academia in one forum, with all the faculties and centers of the SLTC Research University, other local and international universities and research organizations. IRC2024 will be the fourth of its kind, organized and hosted by the SLTC Research University.

The theme "Fostering Multidisciplinary Research for Sustainable Advancement" embraces the IRC 2024 with 10 tracks of multidisciplinary fields such as, Mathematics, Science, and Technology, Electrical, Electronic, Mechanical and Systems Engineering, Information and Communications Technology, Machine Learning, Artificial Intelligence and Robotics, Social Sciences, Humanities, Culture and Education, Sustainable Agriculture, Environment and Food Security, Fashion, Textile and Clothing Technologies. IRC2024 will provide a forum for academics, industrialists, and research students from Sri Lankan universities and institutes to present their research findings at one venue to an audience with high intellectual capacity. The constructive feedback that the researcher would gather from interactive discussions may pave the way to new frontiers in research. Further, the organizing committee hopes IRC2024 will help to spread knowledge and will trigger innovations that are needed to meet the Sustainable Development Goals.

I wish to thank Professor Veranja Karunarathne, the Vice Chancellor and CEO of SLTC, along with the dedicated support of the IRC2024 organizing committee, the Deans of Faculties, Heads of Departments, members of the Senate, and administrative officials.

Therefore, I, on behalf of the Organizing Committee, acknowledge the valuable contributions made by them all, towards achieving our goals. I take this opportunity to extend my sincere appreciation to members of the Organizing Committee, and Members of the Sub-Committees, Editorial Boards, the expert panel of reviewers, sponsors, and all the others who contributed in numerous ways, working tirelessly to accomplish our targets and make this event a great success.

It is my honor and privilege to welcome all the distinguished delegates and researchers to IRC2024 and I hope that you will find the conference extremely productive, interactive, and inspirational.

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Dr. Yashika Jayathunga	Department of Mathematics, University of Colombo

Preconference Webinars

Smart solutions for energy crisis in Sri Lanka

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INTERNATIONAL EDUCATION CONSULTANCY

A pre-conference webinar by:

Dr. Nishan Dharmaweera

Dean
Faculty of Engineering
University of Sri Jayewardenepura

Date : 30, October 2024
Time : 8.00 P.M. (IST)
Register at:
https://bit.ly/IRC2024_Webinar_02

Dr. Nishan Dharmaweera obtained his B. Eng. Degree in Electrical and Computer Systems Engineering with a First Class Honors in September 2009 from Monash University Australia. After finishing the undergraduate studies, he went on to continue his postgraduate studies at the same university. He obtained his PhD degree in the field of telecommunications engineering in 2014. After completing his post graduate studies, he joined the Chalmers University of Technology, Sweden, as a Postdoctoral Researcher in January 2015. Then in October 2016, he joined as a Senior Lecturer in the Department of Electrical and Electronic Engineering, USJ.

International Research Conference, 2024

Sri Lanka Technology Campus

Agenda

6th of November, 2024

8.00 - 8.30 am	Registration
8.30 - 8.45 am	Morning Tea for the Participants/Invitees/Guests
8.45 - 9.00 am	Arrival of the guests and lighting of the oil lamp
9.00 - 9.05 am	Dance item (Pooja Dance)
9.05 - 9.20 am	Welcome Speech by the Vice Chancellor & Chair of IRC2024
9.20 - 10.00 am	Keynote Speech - Dr. Ravi Fernando
10.00-10.05 am	Musical Item by SLTC Music School (Classical Guitar)
10.05-10.15 am	Speech by the Dean, Faculty of Postgraduate Studies & Research
10.15-10.55 am	Keynote Speech – Professor Matsushima Kenichi
10.55-11.00 am	Videos of the Sponsors
11.00-11.05 am	Vote of Thanks - Secretary of IRC 2024
11.05-11.10 am	National Anthem
11.15-13.15 pm	Technical Session 1 & 2
13.15-14.45 pm	Lunch
15.00-17.00 pm	Industry Dialogue
17.00-18.30 pm	Networking Session

7th of November, 2024

8.00 - 9.00 am	Registration
9.00 - 9.10 am	Welcome Speech by General Co-Chair
9.10 - 10.00 am	Morning Tea
10.00 - 11.00 am	Keynote Speech - Prof. Gehan Amaratunga
11.00 - 12.00 pm	Technical Sessions
12.00 - 13.00 pm	Lunch
13.00 - 15.00 pm	Technical Sessions
15.00 – 15.15 pm	Evening Tea
15.15 to 17.00 pm	Closing Ceremony

Keynote on Wednesday

6th November, 2024

Dr. Ravi Fernando

Chairman / CEO of Global Strategic Corporate Sustainability Pvt. Ltd, Board of Directors of Dilma, Melsta Corp, Aitken Spence Plantations and Hotels, LOLC Holdings, Ceylon Graphene Technologies, UN Global Compact LN, Global Strategic Corporate Sustainability Pvt. Ltd

Keynote Title: Sri Lanka from commodity exporter to Science-led, value-added, sustainably made, Global Branded exporter

Every time we undertake any research, we need to do so not simply to meet a requirement for obtaining a degree, but consider how that research can contribute to a new body of knowledge. Ideally a new body of knowledge that can impact the nations GDP positively. If the research project is focused on creating a new product, then it needs to be approached from a blue ocean perspective of creating a new Market space as opposed to a replica of an existing product.

Since independence in 1948, Sri Lanka has been an exporter of commodities. From Tea, Rubber and Coconut to Mass producing women's intimate wear for global brands. The nations commodity mind set over the past 76 years has resulted in the nation being at the bottom end of the value chain. The only exception to the rule has been in the Tea sector where we have established one global FMCG brand of Tea in Dilmah where the brand is available in over 105 nations.

In order to transition from 'commodity exports to branded global exports' we need a change in mind set. That change of mind set must start at the way we approach Research, especially if we are working on a product.

A new mindset required should be anchored in the following:

Science-led *– Proof of concept stands rigor*
Sustainably made *- Renewables /Sustainable materials*
Value-added *– Minimum +50-70%*
Branded *– Not a commodity, a brand*
Global *- Marketed in 100 nations +*
JV *-To leverage cutting-edge technology*
Key steps to achieve the goal

-Identify a market need and create a **BLUE OCEAN MARKET SPACE**. Quantify market

- Identify a **Global technology partner to form a JV** (China leads Green-tech)

- Create **differentiation** that sets the solution /product apart.

- Launch to an identified **test market**, learn from it

-Launch regionally/Globally

Make your research project count for Sri Lanka, select projects that add value to the Nations global competitiveness and create Blue Ocean market spaces.

Keynote on Wednesday

6th November, 2024

Professor Matsushima Kenichi

Professor Ken-ichi Matsushima received his Bachelor of Science degree from the Faculty of Agriculture, Department of Horticulture and Agriculture at **Shinshu University** in 1991. He subsequently graduated from the Graduate School of Agriculture, Shinshu University, in 1993, and later earned his Doctor of Philosophy degree from **Gifu University**. Professor Matsushima has held various research and administrative positions, including at the Ministry of Agriculture, Forestry and Fisheries, the International Affairs Department, Kyushu National Agricultural Experiment Station, and the Rural Development Bureau.

Keynote Abstract

The pungency of chili peppers is due to capsaicinoids produced and accumulated in the placenta and septa within the fruit, and their content is affected greatly by the environment. Our research team investigated how the pungency of chili peppers changes under different environmental conditions, with the aim of controlling the pungency during the cultivation of chili peppers and when breeding new varieties. As a result, it was clearly shown that the amount of moisture applied to the soil, the salinity of the soil, and the air temperature all affect the amount of pungent compounds in the fruit. It was also found that the amount of phosphorus applied to the soil has a deep relationship with the amount of pungent compounds, and that the pungency of the fruit is reduced when there is no phosphorus or too much phosphorus. As a result of research using a variety of chili peppers called “shishito” that are popular in Japan and have extremely low levels of capsaicinoid, it was found that fruits with few seeds due to parthenocarpy are highly variable in terms of their pungency. It was also found that the pungency of these “shishito” peppers is controlled by two loci.

Keynote on Thursday

7th November, 2024

Professor Gehan Amaratunga

Professor Gehan Amaratunga received a B.Sc. degree in Electrical Engineering from the **University of Wales**, Cardiff, U.K. (summa cum laude) and a Ph.D. degree from the **University of Cambridge**, Cambridge, U.K., in 1983.

Keynote Title: Electronic Devices Based on Quantum Properties

Abstract

Gehan A. J. Amaratunga[1,2]

[1]*Zhejiang University – University of Illinois at Urbana Champagne Institute (ZJUI) and School of Information Science and Electronics, Zhejiang University International Campus, Haining, China.*

[2]*Electrical Engineering Division, Department of Engineering, University of Cambridge, UK.*

Up to the present all electronic devices in use, specifically transistors based on semiconductors, are modelled the basis of charge flow under the influence of an electric field (drift) and gradient of charge (diffusion). In calculating the energies available for charge flow the wave properties of electrons are invoked to derive the energy bands, band gaps and energy – momentum (dispersion) distributions of semiconductor materials which are suitable for electronic devices. However, the core operation of an electron device assumes classical electrical-fluid flow, with the quantum behaviour of electrons only used to determine the available energy states.

Due to the performance limits (switching speed and power) posed by technology to manufacture electronic devices solely based on charge flow, for the past 30 years there has been exploration of electronic device concepts which utilise the quantum nature of electrons for switching and by extension computation. Some of these concepts have become particularly relevant in the context of quantum computation which relies on such quantum mechanical behaviour of electrons. The presentation introduces these concepts and looks to how they me applied in electronic devices in general.

Panelists of the Industry Dialogue

Dr. Angelo Karunaratne

Tech and Strategic Operations Lead at Soft Matter

(General Manager),

Twinery – Innovations by MAS

Dr. Angelo Karunaratne, a distinguished figure in the realms of biomedical engineering and wearable technology, has cultivated a versatile career that spans rigorous academic research, dynamic industry leadership, and enterprising ventures. His profound expertise is underpinned by a rich educational foundation with a PhD in Biomedical Engineering and Biomaterial Sciences from Queen Mary, University of London, and further complemented by professional qualifications including Chartered Engineer status from the Institute of Mechanical Engineers, UK.

In academia, Dr. Karunaratne has served as a senior lecturer and visiting consultant at prestigious institutions such as the University of Moratuwa and Imperial College London. His research has led to impactful innovations in biomaterials and medical diagnostics, securing significant grants and accolades including the Health 2.0 Outstanding Leadership Award.

Transitioning seamlessly into the industry, Dr. Karunaratne has excelled as a tech and strategic operations leader at Twinery – Innovations by MAS, where he spearheaded health-tech and wearable tech initiatives. His leadership was instrumental in developing new products and processes that significantly enhanced the company's market presence and operational efficiency.

As an entrepreneur, Dr. Karunaratne's acumen shines through his involvement in startups and innovation hubs, where he mentors burgeoning entrepreneurs. His patents in health and wellness products underscore his capability to transform conceptual ideas into tangible, market-ready solutions.

Dr. Karunaratne's commitment extends beyond professional spheres into community service and sports. He actively engages in training and coaching school and university students, fostering the next generation of scientists and engineers. Additionally, his passion for track and field, particularly javelin throw, has seen him not only compete at masters and mercantile events but also mentor athletes training for Olympic standards.Through a career marked by a visionary outlook, Dr. Karunaratne continues to influence the fields of science and technology profoundly, embodying the spirit of innovation and leadership.

Dr. Lakshitha Pahalagedara

Dean, Faculty of Postgraduate Studies and Research of

Sri Lanka Technology Campus

Dr. Pahalagedara is a strategic innovation leader and a researcher with over 14 years of experience in academic & industrial R&D.

He obtained his PhD from University of Connecticut, USA and BSc (Hons) special degree in Chemistry from University of Peradeniya.

Dr. Pahalagedara has experience in developing novel technologies in the areas of energy, materials science and sustainability and has worked with world renowned companies such as Exonn Mobil, Corning Incorporated and the US Department of Energy during his postgraduate studies.

Dr. Pahalagedara has a proven track record in scientific R&D with over 1300 citations and is an inventor of two US patents.

He is also an expert in strategizing business models to create an innovation eco-system integrating science, technology and commercialization. Before joining SLTC Research University Dr. Pahalagedara worked as a Senior Manager at Sri Lanka Institute of Nanotechnology (SLINTEC).

He currently serves as the Dean, Faculty of Postgraduate and Research of Sri Lanka Technology Campus and as a member of the Board of Study of the Postgraduate Institute of Science at University of Peradeniya.

Ms. Piyumi Perera

General Manager Design, Hirdaramani Group

Piyumi Perera is a seasoned fashion design and product professional, who drives strategic business growth by embracing new commercial design technology. As a **General Manager Design for Hirdaramani Group**, she draws from over 25 years of experience in the global apparel industry.

Her working experience spans from Canada to Sri Lanka, where her focus has been on commercial fashion design for some of the world's leading global brands. Her product design experience, ranges from intimates, sleepwear, casual sportswear and kids wear, while now specializing in sustainable denim, at **Hirdaramani Discovery Lab**. She has set up and led creative teams, for supply chain-based design since 2006.

In 2020, she was selected as one of the top 50 influencers in the global denim Industry, "**Rivet 50"**, by the Sourcing Journal. She was part of the team that worked on making denim circular, in the Jeans Re- Design project by the Ellen MacArthur foundation in 2019. She was featured in the mini documentary alongside key industry and brand leaders.

She is a strong advocate for Sri Lankan design talent and has served as a visiting lecturer at the Faculty of Textile Technology at the **University of Moratuwa**. Additionally, she has been involved in lectures and project evaluations at the Academy of Design."

Professor Roshan Ragel

Head, Department of Computer Engineering, Faculty of Engineering, University of Peradeniya.

Dr Ragel was appointed a Senior Lecturer in Computer Engineering at the University of Peradeniya in December 2007 and has been a Professor since October 2017. He has been a Professional Member of the IEEE and IEEE Computer Society since 2005 and a Senior Member since 2014. He is also a Professional Member of the Association of Computing Machinery (ACM).

Prof Ragel has co-authored over 200 peer-reviewed articles on Internet of Things, Wearable Computing, Bioinformatics, and Artificial Intelligence and Machine Learning. He has won several best paper awards in conference papers, the most prolific Sri Lankan author award from Elsevier Research in 2017 and the Presidential award for scientific publication in Sri Lanka in 2018 and 2023. He was also named the top scientist in computer science in Sri Lanka by the AD Scientific Index in 2021 and 2022 and the best computer scientist in the country in 2023 and 2024. He was a visiting research scholar at the UNSW – Sydney many times, QUT – Brisbane, UIUC – Illinois and ANU – Canberra once each.

Prof Ragel has been the consulting chief executive officer at the Lanka Research and Education Network (LEARN), the national NREN, since 2017. With his involvement, LEARN was able to step up for a significant milestone by launching the Asi@Connect Project in Sri Lanka in 2017, which brought many opportunities for the LEARN Research and Education (R&E) network community to get involved in utilising the project resources and funds. He has represented Sri Lanka in the Asi@Connect Governors meeting and has been a Council Member of Asia Pacific Advanced Network (APAN) since 2017. Since 2020, he is also the Vice-Chair of the Asi@Connect Steering Committee. With COVID-19 lockdowns, LEARN is helping the university community in the country connect and engage in productive research and education activities online.

At the National level, Prof Ragel was a Core Group member for Higher Education at the Presidential Task Force for Education, which was established in 2020. He is a member of the UGC Standing Committee on the Development of IT Infrastructure and Online Education and the UGC-appointed committee to develop the Concept of Virtual / Hybrid University. He also serves as a member of the Presidential Committee to Formulate the AI Strategy for Sri Lanka, a committee formulated recently with the advancement of Generative AI. He is also a founder of the AI Forum for Academics (AIFA). This academic syndicate explores the opportunities and challenges of GenAI in Higher education based at the University of Peradeniya.

Technical Programme

Date: Wednesday 6th November 2024 |Track: Management Sciences			
Track	Time	Paper ID	Paper Title
Venue: Main Hall Mode: Oral Presentation			
Management Sciences	11.00 AM - 11.15 AM	16	Factors Affecting the Effectiveness of Cross-Generational Collaboration in the Maritime Industry in Sri Lanka
	11.15 AM - 11.30 AM	31	The tourist's perception and uniqueness of the Sri Lankan tea tourism experiences with reference to Nuwara Eliya District in Sri Lanka
	11.30 AM - 11.45 AM	69	FINANCIAL DEVELOPMENT AND ENVIRONMENTAL DEGRADATION IN THE SOUTH ASIAN REGION
	11.45 AM - 12.00 PM	72	THE IMPACT OF DIFFERENT CORPORATE EVENT ANNOUNCEMENTS ON SHORT-RUN STOCK RETURNS; EVIDENCE FROM COLOMBO STOCK EXCHANGE
	12.00 PM - 12.15 PM	84	Recruitment: Can Artificial Intelligence be the next Human Resources Manager?

Date: Wednesday 6th November 2024 |Track: Machine Learning, Artificial Intelligence and Robotics			
Track	Time	Paper ID	Paper Title
Venue: Shire | Mode: Oral Presentation			
Machine Learning, Artificial Intelligence and Robotics	11.00 AM - 11.15 AM	13	Deep Learning- Aided Wireless Communication
	11.15 AM - 11.30 AM	19	Enhancing Stock Price Forecasting on the Colombo Stock Exchange with Cluster-Based Gated Recurrent Unit Architectures
	11.30 AM - 11.45 AM	55	A Machine Learning-Based Personalized Outfit Recommendation System Integrating Skin Tone Classification and Size
	11.45 AM - 12.00 PM	62	Automated Number Plate and Parking Spot Detection using Computer Vision Techniques
	12.00 PM - 12.15 PM	71	Sentiment Analysis for Amazon Reviews to Identify Customer Interests
	12.15 PM - 12.30 PM	82	ScholTex- NLP-based Tool to Detect and Provide Suggestions to Correct Inconsistencies in Scholarly Writing
	12.30 PM - 12.45 PM	9	Intelligent Road Safety Navigation in Sri Lanka: A Review of Machine Learning Techniques and Proposal of a Model for Predicting Accident Hotspots and Severity
	12.45 PM - 1.00 PM	58	Comparative Analysis of BER Performance in UAV-assisted THz Communication Systems with Different Modulation Schemes

Date: Thursday, 7th November 2024 |Track: Mathematics, Material Science and Technology			
Track	**Time**	**Paper ID**	**Paper Title**
Venue: Satellite Building, GF1| Mode: Oral Presentation			
Mathematics, Material Science and Technology	11.00 AM - 11.15 AM	6	Edge-Magic Total Labelling of Cyclic and Bicyclic Bridge Graphs
	11.15 AM - 11.30 AM	47	A Survey on Fuzzy Multi Objective Linear Programming And Its Applications
	11.30 AM - 11.45 AM	57	Optimizing nitrogen doping in graphene oxide for superior WS2-based hydrogen evolution catalysts
	11.45 PM - 12.00 PM	8	A Novel Factorization Method Using Continued Fractions
	Lunch		

Date: Thursday, 7th November 2024|Track: Electrical, Electronic, Mechanical and Systems Engineering			
Track	**Time**	**Paper ID**	**Paper Title**
Venue: Research Building, FF2 | Mode: Oral Presentation			
Electrical, Electronic, Mechanical and Systems Engineering	11.00 AM-11.15 AM	1	Incorporating the signal processing elements in the development of an automatic tire inflation system
	11.15 AM-11.30 AM	2	OPTIMIZING THE CONCEPTS OF SOLAR WATER DISTILLATION SYSTEM FOR RURAL COMMUNITIES IN SRI LANKA
	11.30 AM-11.45 AM	18	Design and Computational Fluid Dynamics Study of Hybrid Vertical Axis Wind Turbine by Combining Savonius and H-Darrieus Rotor System
	11.45 AM-12.00 PM	33	Indoor Positioning Using Visible Light Communications

	Lunch		
	1.00 PM - 1.15 PM	39	Bioinformatic Assessment of KCNN4 Gene Expression as a Prognostic Marker in Pancreatic Adenocarcinoma
	1.15 PM - 1.30 PM	60	Dependence of Electrolyte Medium to Performance of Reduced Graphene Oxide (R-GO) based Supercapacitor
	1.30 PM - 1.45 PM	67	A 78.3% Efficient Power Management System Using FOCV-Based MPPT for Thermoelectric Powered IoT Applications
	1.45 PM - 2.00 PM	74	Supercapacitor Assisted Maximum Power Point Tracker (SCA MPPT)
	2. 15 PM - 2.30 PM	75	LED to LED MISO (Multiple Input Single Output) VLC System
	2.30 PM - 3.00 PM	83	Smart Driving Assistance System for Expressway Safety

Date: Thursday, 7th November 2024 |Track: Sustainable Agriculture, Environment (Agriculture)			
Track	**Time**	**Paper ID**	**Paper Title**
Venue: Research Building, FF3 | Mode: Oral Presentation			
Sustainable Agriculture, Environment (Agriculture)	11.00 AM - 11.15 AM	53	Effect of Potassium Levels on Yield and Biochemical Properties of Hydroponically Grown Lettuce Varieties
	11.15 AM - 11.30 AM	54	Investigation of The Effects of Abiotic Stress on the Biochemical Compounds and The Anti-microbial Activity of Origanum vulgare (Oregano) in Sri Lanka
	11.30 AM - 11.45 AM	86	Detecting Phosphorus Levels in Paddy (Oryza sativa) Using Computer Vision: A Precision Agriculture Approach

	11.45 AM - 12.00 PM	87	Evaluating Soil Properties in Coconut-Based Agroforestry Systems Intermediate Zone of Sri Lanka
	Lunch		
	1.00 PM - 1.15 PM	88	Developing an Effective Vegetative Propagation Method for Commercial Cultivation in Gurmar Plant (Gymnema sylvestre)
	1.15 PM - 1.30 PM	89	Estimation of photosynthesis active radiation (PAR) distribution by coconut-based different intercropping models
	1.30 PM - 1.45 PM	91	Optimization of Multiplication and Initiation Media for Anthurium Maine using Growth Regulators
	1.45 PM - 2.00 PM	97	Identifying High-Quality Cost Effective Growing Media to Enhance Mushroom Production in Sri Lanka
	2. 15 PM - 2.30 PM	96	Find out a cost-effective organic fertilizer mixture as a solution for leaf yellowing of the Calathea insignis.

Date: Thursday, 7th November 2024 |Track: Sustainable Agriculture, Environment (Environment)			
Track	**Time**	**Paper ID**	**Paper Title**
Venue: Research Building, FF5| Mode: Oral Presentation			
Sustainable Agriculture, Environment (Environment)	11.00 AM - 11.15 AM	48	Assessing Tree Diversity and Vegetation Composition in Wet Lowland Rice Field-Associated Eco Units in Pelawatta, Sri Lanka: A Comparative Study of Rice Field Integrated Home Gardens, Kalavita, and Owita Systems
	11.15 AM -	49	Amphibian Diversity as an Indicator of Ecosystem Maturity: Comparative Studies in Five Different Ecological Seral Stages at the Belipola

	11.30 AM		Analog Forest, Sri Lanka
	11.30 AM - 11.45 AM	68	Assessment of Land Use Changes on Vegetation Dynamics in Muthurajawela Wetland: A GIS-Based Spatio-Temporal Study
	11.45 AM - 12.00 PM	59	Design Conceptualization of Food Waste Decomposer Using Quality Function Deployment and Pugh Method
	Lunch		
	1.00 PM- 1.15 PM	90	The effects of Silica Gel on the Properties of Municipal Waste Compost Pellets
	1.15 PM- 1.30 PM	77	Sustainable Waste Management in the Paint and Coatings Industry: A Case Study of a Paint and Coatings Manufacturing Company in Sri Lanka
	1.30 PM- 1.45 PM	70	Assessing Greenhouse Gas Emissions from Integrated Rice-Crop Systems in the Dry Zone of Sri Lanka: A Case Study in Ampara District
	1.45 PM- 2.00 PM	105	Develop an Allometric Model to Estimate Total Carbon Sequestration Potential of Coconut Cultivation
	2. 15 PM - 2.30 PM	85	An Anlysis between Flood Damage and Economic Growth in Bangladesh Amid Changing Precipitation Dynamics
	2.30 PM- 3.00 PM	93	Assessment of the Status of Microbiota Characteristics, Physico-Chemical Characteristics, Water Quality Index, and Trophic Level Index at Beira Lake, Colombo, Sri Lanka
	3.00 PM- 3.15 PM	92	Cluster Analysis of Microbial, Physico-Chemical Characteristics, Water Quality Index (WQI) and Trophic Level Index (TLI) for Water Quality Assessment of Beira Lake, Colombo, Sri Lanka

Date: Thursday, 7th November 2024 |Track: Sustainable Agriculture, Environment (Food)			
Track	**Time**	**Paper ID**	**Paper Title**
Venue: Research Building, GF5| Mode: Oral Presentation			
Sustainable Agriculture, Environment (Food)	11.00 AM - 11.15 AM	99	Investigate the Water Purification Properties of Potatorum (Igini) Seeds Powder, Moringa Oleifera Seeds Powder and Charcoal Powder
	11.15 AM - 11.30 AM	76	Development of Chai Tea- Flavored In-bottle Sterilized Milk
	11.30 AM - 11.45 AM	79	Enhancing the Sensory Attributes of Yoghurt Using Fortification of Ginger (Zingiber officinale Roscoe) Extract
	11.45 AM - 12.00 PM	50	Harvest-wise Comparison of Nutrient Content, Antioxidant and Antimicrobial Properties of Pleurotus ostreatus Cultivated on Rubber Sawdust Media.
	Lunch		
	1.00 PM- 1.15 PM	51	Postharvest Loss Assessment of Leeks from Farmgate to The Retailer Market in Sri Lanka (A Case Study)
	1.15 PM- 1.30 PM	46	Utilizing Hypocotyl Color as a Phenotypic Marker for Enhancing Disease Resistance and Fruit Quality in Solanum lycopersicum F3 Generation: A Pedigree Selection Study Focused on Phytophthora infestans and Alternaria solani
	1.30 PM- 1.45 PM	61	Advanced Yield Prediction in Rice Using UAV-Multispectral Imaging and Machine Learning Approaches in Sri Lanka

Date: Thursday, 7th November 2024 |Social Sciences, Humanities, Culture and Education			
Track	**Time**	**Paper ID**	**Paper Title**
Venue:Satellite Building, FF3 | Mode: Oral Presentation			
Humaities and Social Sciences, Culture and Education	11.00 AM - 11.15 AM	**104**	Investigating the Determinants and Impact of Occupational Stress on Employee Well-Being and Organizational Performance.
	11.15 AM - 11.30 AM	**28**	Legal Aspects of Copyrights Responding to Artificial Intelligence : A Comparative Analysis of EU in Sri Lanka
	11.30 AM - 11.45 AM	42	Motivation and Resilence while working towards career goals in the absence of immediate job opportunities
	11.45 AM - 12.00 PM	24	Balancing Work and Life: Exploring Disconnect in Sri Lanka through Comparative Analysis wtih France and Australia
	Lunch		
	1.00 PM - 1.15 PM	38	The Correlation between Dengue Incidence and Rainfall in Badulla, Devisional Secretariat in Badulla District, Sri Lanka
	1.15 PM - 1.30 PM	73	Analyzing the Factors Influencing the Persistence of Undergraduates at ABC Private Higher Education Institute

Date: Thursday, 7th November 2024 |Fashion, Textile and Clothing Technologies			
Track	**Time**	**Paper ID**	**Paper Title**
Venue: Satellite Building, GF2 | Mode: Oral Presentation			
Fashion, Textile and Clothing Technologies	11.00 AM - 11.15 AM	64	Assessing the Effectiveness of Existing Marketing Strategies in Fashion Product Promotions: A Qualitative Study
	11.15 AM - 11.30 AM	98	Enhancing Sustainable Development Through Post Consumer Textile waste Recycling: Improving Human Well-being
	11.30 AM - 11.45 AM	100	Evaluating Consumer Perceptions and the Physical Performances of Recycled Textiles: Sri Lankan Apparel Consumers in Perspective
	11.45 AM - 12.00 PM	101	Reducing Cycle Time of Raw Material Sourcing for Accelerated Supply Chains in Sri Lankan Apparel Industry
	12. 00 PM - 12.15 PM	102	Enhance the Online Fashion Purchasing Behaviour among Digital Seniors: Qualitative Study
	Lunch		

Poster Session

Thursday 7th Nov 2024, Research Building at 1.00-3.00 pm

Paper ID	Paper Title
4	ANALYSING THE EFFICACY OF BLOCKCHAIN TECHNOLOGY IN ENHANCING CORPORATE GOVERNANCE PRACTICES: A CASE STUDY OF SRI LANKA
5	Key Enablers of Successful Adoption of Agile Project Management in FMCG Industry
6	Edge-Magic Total Labelling of Cyclic and Bicyclic Bridge Graphs
7	Evaluating the Efficacy of Machine Learning Compared to Traditional Methods in Kidney Calcification Diagnosis: A Comprehensive Review
10	Antecedents of internal stakeholder satisfaction of agile projects: Evidence from the Sri Lankan software industry
15	Systematic Review of Smart Home Automation Technologies Based on IoT
21	Enhancing Unity Games with Secure Cloud Authentication and Automated Progress Saving
23	A Systematic Literature Review of Weather-Driven Solar Energy Forecasting: Advanced Predictive Analytics
25	The Intelligent Flyer Image Generating System for Event Promotions
26	The Intelligent Flyer Image Generating System for Specific Event Promotions
27	Review of Smart Air Pollution Monitoring System
29	Examining the Ethical and Legal Implications of Extending Intellectual Property Rights to AI and Robots in Sri Lanka: A Comparative Study
30	Enhanced Cybersecurity: Detecting ARP Spoofing Using Machine Learning Techniques.
32	Adaptive Traffic Control Framework for Urban Intersections
34	Revolutionizing Agricultural Commerce in Sri Lanka A Multi-Vendor E-Commerce Platform with AI-Driven Advisory Services
35	Automated Students Check-in System With Effective Parent Communication

36	Transforming Healthcare with E-Prescription Systems: A Review of Security, Privacy, Benefits, Challenges, and Technological Advancements
37	A Systematic Review of Machine Learning and Deep Learning Approaches in CT Based Lung Cancer Detection and Prognosis
40	Banana Postharvest Loss Assessment in Sri Lanka
41	A Review in Morphology, Health Benefits and Propagation Methods of Selected Medicinal Plants in Sri Lanka
44	VLC Link Distance Enhancement Using Channel Coding Techniques
45	A Critical Analysis of Fertilizer Allocation Models for Managing Phosphorus in Vegetable-Growing Lands in Up-Country Sri Lanka
47	A Survey on Fuzzy Multi Objective Linear Programming And Its Applications
52	A Review of the Role of Soil Microbiomes in Enhancing Crop Productivity
56	Dual-Axis Solar Tracking System with Increased Efficiency
63	Voice Activated Surgery Assist Robot
66	Liquid limit & Plastic limit Variation with the Fine-sand Content
80	The Impact of Artificial Intelligence in Shaping Primary School Education
81	Effect of film thickness on characteristic properties of thermally evaporated copper oxide thin films
94	An Assessment of Carbon Sequestration and Biodiversity using the Shannon-Weiner Index of Trees for Sustainable Urban Campus Management: A Case Study at Sri Lanka Technology Campus
95	Effect of Different Organic Manures and Organic NPK on Growth and Yield of Radish (Raphanus sativus L.)
103	Fabrication of ZnO Nanowires Using Chemical Bath Deposition at Different pH Levels for High-Performance Humidity Sensors
106	Development of an Autonomous and Controllable Plowing Machine via Mobile Application
108	Advanced Thin Film Fabrication Using Ultrasonic Atomized Spray Pyrolysis Deposition (UASPD) for ZnO thin layer preparation
109	Six-Key ASCII-Braille Converter with Real-Time Audio and Tactile Feedback for Visually Impaired Communities

FULL PAPERS

Machine Learning, Artificial Intelligence and Robotics

DreamyMirror: A Machine Learning-Based Personalized Outfit Recommendation System Integrating Skin Tone Classification and Size

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***Abstract*—Due to the increasing popularity of e-commerce, buying has undergone a tremendous shift and belongs to a different world. ” But there is still some difficulties with personalization when it comes to the proposed size and the choice of the color taking into consideration the skin color of the person. In this paper, the authors introduce DreamyMirror, a novel system for recommending outfits based on the individual user’s skin tone and size, along with allowing for virtual fitting. Based on a skin tone classifier CNN model built from CelebA database and a pre-trained Pose_iter_440000 of OpenPose. size prediction caffemodel, DreamyMirror provides unique suggestions of outfits according to the appearance of the person. The system also contains the Virtual Try on system wherein users can anticipate what the selected apparels look like at a glance. The proposed system can automatically recognize skin tone with an overall classification accuracy of 92% and the size prediction accuracy is found to be 95%. Moreover, the user engagement metrics also show an 85% level of satisfaction with the features – this is about the virtual try-on. This work shows how the application of AI in fashion retail can help better engage the customer through a truly individualized shopping experience and, at the same time, minimize the return rate because of the wrong size or color choice**

Keywords— ***machine learning, personalized recommendation system, skin tone classification, size prediction, virtual try- on, fashion technology.***

I. INTRODUCTION

Digital commerce now plays a great role in fashion retailing and people are now shifting towards online shopping, thanks to technology. Nevertheless, the absence of personalization in today’s e-commerce remains a major challenge which has been a major drawback in fashion e-commerce because customers are unable to get apparel that fits the right size, color, and complexion for them. Also, the fact that consumers cannot touch and feel the clothes they would want to buy leads to higher returns and both the consumer and the retailer are unhappy in the end.

To overcome these challenges, this paper presents the DreamyMirror, an efficient and fully integrated recommendation framework for personalized outfit organization, including skin tone analysis, and clothes size prediction, as well as the feature of virtual clothing try-on. The main purpose of the system is to reinforce the concept of online fashion retail by giving the user outfit recommendations according to their appearances. In other words, DreamyMirror addresses concerns that may cause shoppers to be dissatisfied and lead to higher return rates both online and in-store buying experience by providing a skin tone and size prediction solution that is easy to use.

In this paper, we describe the DreamyMirror system which includes the specifications, implementation, and assessment of the utilized Machine learning models, datasets, and overall system design. Furthermore, the system is validated against the current solutions highlighting the effectiveness of the proposed framework to deliver effective and dressed fashion recommendations.

II. METHODOLGY

The DreamyMirror system utilizes multiple machine learning algorithms to provide articles of clothing recommendations of the user’s skin tone and body measurements. The methodology for developing this system is divided into three key components: image categorization, sizing, and virtual fitting.

2.2 SYSTEM ARCHITECTURE DIAGRAM

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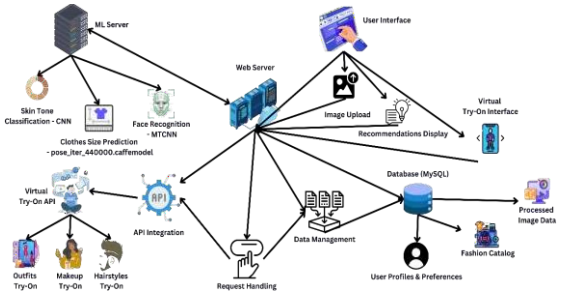

A. System tone classification

The primary objective of the DreamyMirror system is to recommend clothes that would best fit the user's skin tone. About this, various skin tones are important in the definition of the colors as well as the kind of dresses suitable for human beings. To this end, there is the use of Convolutional Neural Network(CNN), a mathematical model that can pass on data to different layers and recognize images.

Based on the CelebA data set the CNN is trained with over 200k images of celebrities where each image is tagged with 40 attributes including skin tone. The problem of a great

variability of the skin tone is solved by the great variability of the dataset used which helps the model improve its generalizability. For this study, skin tones were grouped into three primary categories: Another one was normal, which has three categories including Fair Light, Medium Tan, and Dark Deep. The classification process comprises several key steps, which include the data pre-processing step, the training step, and the evaluation step.

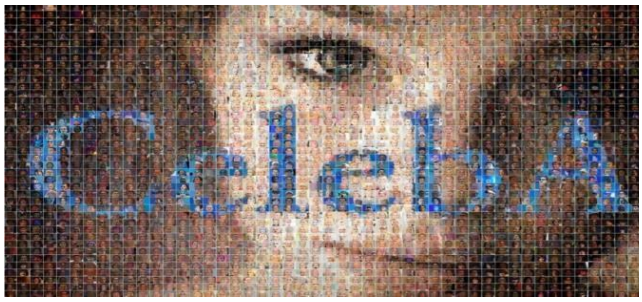

Figure 2: Large-scale CelebFaces Attributes (CelebA) Dataset

Face Detection and Cropping: MTCNN (Multi- task Cascaded Convolutional Networks)

Face Detection and Cropping: MTCNN (Multi-task Cascaded Convolutional Networks) was used to detect and crop facial regions from the images for accurate skin tone analysis. MTCNN is a robust face detection framework that effectively isolates facial features, ensuring that the skin tone analysis is focused on the most relevant parts of the image.

Figure3: Face Detection Sample

Data Preprocessing: The CelebA dataset images are preprocessed before it is used to train the CNN before training the CNN. This means, reducing the size of all the images to have the same size so that they have preprocessed input data size of 64X64. These pixel values are then scaled to the range of [0,1] this enhances the efficiency as well as the convergence rate of the CNN while training. Finally, to increase the data size and overcome overfitting, stochastical data enhancement methods including images rotation, flipping and zooming are employed.

Figure4: Dominant Color Extraction using K-Means Clustering

Model Architecture: In CNN architecture we have multiple numbers of convolutional filter layers, pooling layers, and fully connected layers. The convolutional layers basically learn spatial hierarchies of features from the input images in a cascade and a higher level representation of the data is learnt at each level. These features are then fed into pooling layers where dimensionality of the data is reduced thus making the model computationally efficient. Lastly, the fully connected layers reorganize the learnt features into the three skin tone classes.

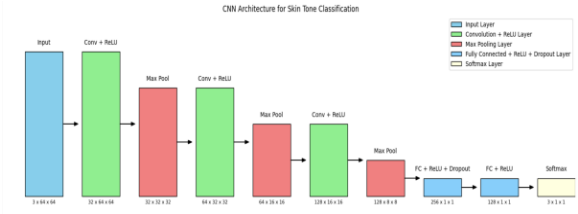

Figure 5: CNN Model Architecture

Training and Evaluation:

The CNN is trained using a labeled subset of the CelebA dataset, with performance evaluated on a separate validation set. The primary evaluation metrics include accuracy, precision, recall, and the F1-score. The model achieved an overall classification accuracy of 92%, with high precision and recall values across all three skin tone categories.

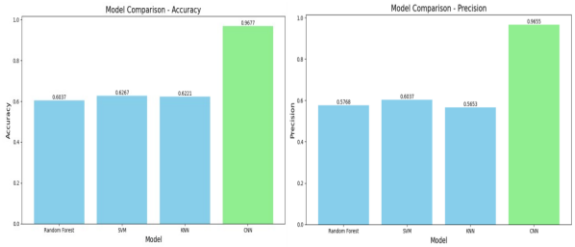

Figure 6: Model Comparison Accuracy and Precision

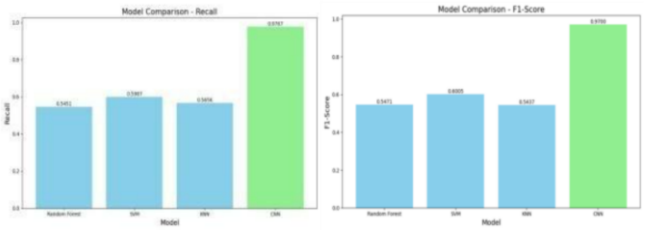

Figure 7: Model Comparison – Recall and F1-Score

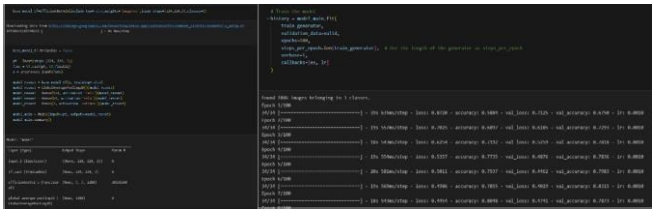

Figure 8: Model Training Process image and Model Training Process

B. Size Prediction

Accurate estimation of size is important in that it helps the firm meet the needs of the customers and reduce issue of returns. DreamyMirror uses a pose estimation model Pose_iter_440000. Equivalent to the size estimation, the clothing sizes of the user are predicted through the so-called caffemodel which is also an element of the OpenPose.

Key Point Detection:

pose estimation model looks for different joints and important points in the body such as the shoulder, elbow, hips, knee, and so on. These key points are then used to determine body measurements such as the shoulder width, the length of the torso, and the length of the legs. This is because deviations about key point detection determine the size of the clothes suggested to fit the dimensions of the users.

Size Prediction Algorithm:

Afterward, the extracted body key points are processed with a regression model to determine the correct clothing size. The regression model is trained on the dataset of body measurements and sizes of clothes that correspond to those measurements, which makes it possible to get the predicted size (Clothing size tags – Small, Medium, Large) according to the user's body parameters. The current model achieves better results for the clothing size recommendation with a precision level of 95% while the conventional size recommendation system depends more on user- provided measurements.

Virtual Try-On

The last constituent of the DreamyMirror system is the Virtual Try-On that enables users to preview needed outfits on them. This is because, through the augmented reality feature, users can have the feel of looks they Stand a Chance of getting when they buy apparel, hairstyles, and makeup products.

The try-on procedure applies external APIs to place images of clothes on the top of the user's picture. The process involves several steps:

1. User Image Acquisition: How it works: Users provide a frontal photo of themselves to the DreamyMirror platform.
2. Clothing Item Mapping: This allows the system to identify from the extracted body key points, the correct position to pose the clothing items on the user's image.
3. Realistic Rendering: State-of-the-art image processing methods are used to model the clothing items including the effects like light and shade and texture of the fabric.

The virtual try-on additionally enhances the consumer confidence in the clothing articles and their abilities to fit properly and look as envisaged by the designers; increasing consumer satisfaction.

III. RESULTS

In order to quantify the performance of the DreamyMirror system, the system response time obtained through experimentation along with the user feedback was used. Skin tone accuracy along with size prediction and virtual try-on were evaluated based on real-life user data against the proposed system.

1. Quality of Skin Tone Classification Outcomes

All skin tone categories' precision, recall, and F1- scores were greater than 90%, and the skin tone classification CNN model accuracy stood at 92%. Performing the confusion matrix for the classification carried out showed that there were very few cases of misclassification thus going on to show that the model is both viable and accurate in predicting skin tone from the images provided.

The proposed model was compared with other predictive models, for example, Random Forest, Support Vector Machine (SVM), and k-nearest Neighbors (k-NN), on the same dataset. These models gave satisfactory results but as seen the CNN model outperforms the rest in all the parameters, especially in accuracy and validation metrics.

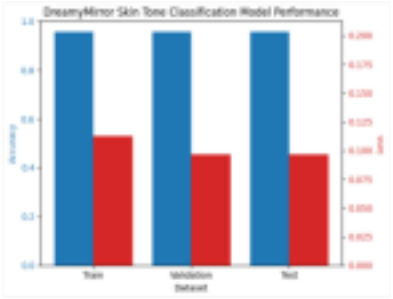

Figure9: CNN Model Performance Chart

Metric	Random Forest	SVM	k-NN	CNN
Accuracy	0.6037	0.6267	0.6221	**0.9567**
Precision	0.5768	0.6037	0.5653	**0.9655**
Recall	0.5451	0.5987	0.5656	**0.9767**
F1-Score	0.5471	0.6005	0.5437	**0.9700**

Model Performance Table

Figure10: CNN Model Performance report and Model Save

Confusion Matrix: The confusion matrix in Figure 11 and 12 shows the number of correct and incorrect classifications for each class and each model.

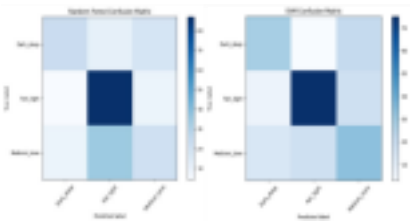

Figure11: Random Forest Confusion Matrix and SVM Confusion Matrix

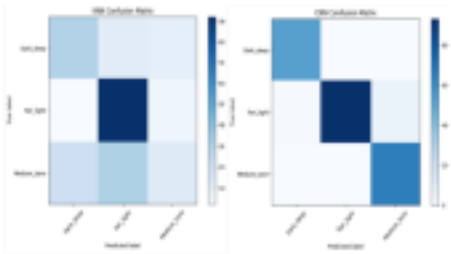

Figure12: KNN Confusion Matrix and CNN Confusion Matrix

Training and Validation Curves: The accuracy and loss curves for training and validation sets are depicted in Figure 40 and 41 illustrating the model's learning process.

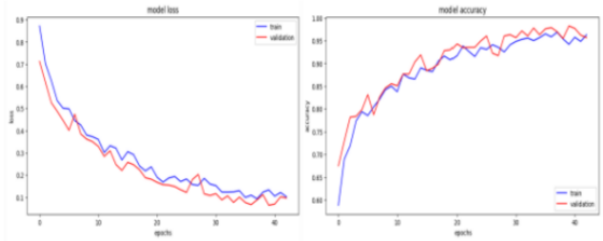

Figure13: CNN Model Loss and Accuracy

B. Size Prediction Results

The size prediction model posited had a very high level of precision whereby the average precision recorded was at 95%. And it was possible to check how well the model works for body key points identification and corresponding clothing size prediction with the help of a separate set of images with known measurements. The results showed that the recommended sizes were true to size and users had a highly improved experience with size prediction compared with conventional e-commerce systems.

Figure14: Size Prediction Result

C. Virtual Try-On Results

Regarding the virtual try on type of feature, 85% of the users pointed out that they benefited from the feature while making purchase decisions. Virtual try- on also led to higher user interaction with larger session durations, higher activity rate compared to that observed for typical e-commerce websites. Of course, customers noted that such an approach allowed them to see what clothes may fit them, which greatly contributed to the increase in trust to the chosen products.

Outfit Tryon Results

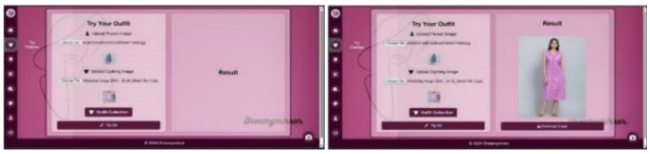

Figure15: Outfit Tryon Result

Makeup Tryon Results

Figure16: Makeup Tryon Result

Hairstyle Tryon Results

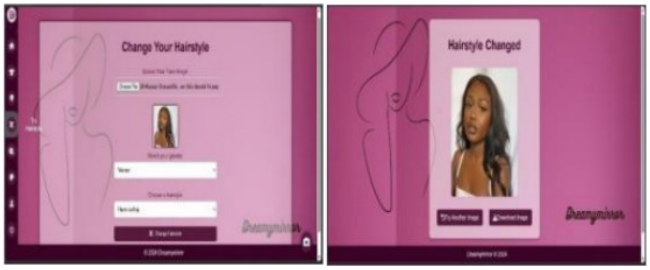

Figure17: hairstyle Tryon Result

IV. Conclusion

The DreamyMirror system implements machine learning in fashion technology for the first time and creates a new way to tackle the much-studied problems in the fashion e-commerce business. One unique aspect of the system is that it is possible to obtain highly specific outfit suggestions concerning skin tone, as well as the size of the body, which is not the case with most existing solutions. This double- tiered approach guarantees its users that in addition to the proper deliverance of their body measurements, they will also be offered clothing that will not only fit them well but also enhance the color of their skin, an area of concern that available e-commerce platforms do not consider.

What's unique about DreamyMirror is that it incorporates several new machine learning approaches such as CNN in skin tone category and PM in its size prediction pose estimation model that are combined to provide a fully customized shopping experience. In addition virtual fitting feature brings a further level of interactivity where clothing, makeup, and hairstyle changes can be applied and previewed in real-time thus increasing the user engagement as well as the decision-making processes that may not have been observed in other similar systems.

The percentile accuracy of this system in the identification of skin tone (92%) and size (95%) puts this system as one of the most accurate systems in the fashion industry. The virtual try-on, based on real-time image processing and body key point mapping, provides the final touch of augmenting the actual try- on experience in a way that is not possible with recommendation systems.

The concept of DreamyMirror is not only in customization: Its ability to help prevent return rates by providing a user size and color identification holds a potential that may revolutionize most e-commerce businesses. Moreover, relying on the availability of real-time response systems, DreamyMirror can adapt to client feedback and stay relevant for as long as clients are satisfied.

V. Acknowledgment

Thanks also goes to the supervisor of this project, Dr. Sampath Deegalla for giving his encouragement, direction, and tips constantly while developing the DreamyMirror system. That is why his contribution was most valuable as his experience influenced the course of the project.

Gratitude is also extended to the co-supervisor Dr Mohammed Azmeer for his useful comments and valuable input that immensely improved the quality of the study. Special thanks are due to the Sri Lanka Technological Campus (SLTC), especially to the resources, which were made available and the environment that prevailed that saw this project to fruition. In light of this, many thanks go to family and friends for their encouragement, support, and patience throughout this process.

References

[1] M. Kawulok, J. Nalepa, K. Kawulok, A. Smolka, and B. Smolka, "Deep features and color analysis for skin detection in variable lighting conditions," *IEEE Access*, vol. 6, pp. 52021–52036, 2018.

[2] S. Chen, J. Zhang, and Y. Li, "Machine learning-based fashion recommendation system: A survey," *IEEE Transactions on Knowledge and Data Engineering*, vol. 32, no. 7, pp. 1317–1330, Jul. 2020.

[3] Z. Li, J. Tang, X. Ding, and J. Wu, "Fashion analysis and clothing recommendation using convolutional neural networks," *IEEE Transactions on Multimedia*, vol. 20, no. 9,

[4] pp. 2383–2395, Sep. 2018.

[5] Y. Zhang, H. Jiang, S. Yang, and Y. Fu, "Outfit visualization and recommendation with cross-domain compatibility modeling," in *Proc. IEEE Conf. Comput. Vis. Pattern Recognit. (CVPR)*, 2020, pp. 7367–7376.

[6] C. P. Santos, L. D. Neto, and A. H. Tavares, "Size recommendation in fashion e- commerce using deep learning," in *Proc. IEEE Int. Conf. e-Bus. Eng.*, 2020, pp. 72–76.

[7] T.-Y. Liu, M.-Y. Chi, and T. Song, "Personalized fashion recommendation model based on skin tone classification," *IEEE Access*, vol. 8, pp. 123456–123465,

[8] 2020.

[9] P. Agrawal and S. Jain, "Virtual try-on using image-based garment transfer with deep learning," in *Proc. Int. Conf. Pattern Recognit. (ICPR)*, 2020, pp. 89–96.

[10] S. Ha, H. Jang, and J. Kim, "Multi-attribute clothing recommendation system using hybrid filtering," *IEEE Access*, vol. 7, pp. 17156–17167, 2019.

The Impact Of Different Corporate Event Announcements On Short-Run Stock Returns; Evidence From Colombo Stock Exchange

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***Abstract* - Publicly traded markets function as the base of our economic system. Efficiently valued financial markets power up national development according to Malkiel (2010). Market effectiveness shows precise security assessment results. When information travels rapidly into stock prices in an efficient market it won't help investors earn more than the market or find ways to get abnormal returns from what they already know.**

This paper examines the efficiency of the market in relation to four prominent corporate events: We examine the information event impact of stock dividend announcements alongside bonus issues, rights issues, and stock splits under Sri Lanka's conditions. A sample of 13 stock dividend and 9 bonus issue releases formed the base data alongside 31 rights issue and 29 stock split announcements. This research uses market model event studies to track price reactions through Average Abnormal Returns and Cumulative Average Abnormal Returns calculations. The research discoveries question what current market efficiency stories tell us.

Investors in Sri Lanka currently lack complete data about stock price reactions to corporate news. Our study examines market reactions to corporate event announcements in CSE using 82 unique events across 14 economic zones between 2019 and 2021.

Keywords—capital markets, corporate announcements, event study methodology, market efficiency, semi-strong form of efficiency, Colombo Stock Exchange (CSE).

Introduction

The capital market plays a fundamental role in economic growth across every nation. People see the capital market as the main indicator of how the economy performs. The Colombo Stock Exchange leads Sri Lanka's economic growth by playing a decisive role. Through its role as exchange manager the CSE emerges as both an important emerging market for its region and for developing countries. Fortune Magazine ranked Sri Lanka as the second global market showing great potential for growth in 2009.

Stock market performance reacts to different elements including business developments and results alongside market trends and investor beliefs alongside overall market conditions. The multiple influencing elements determine stock price changes so studying stock market movements helps discover what specifically drives these changes. Companies send out vital market information through their event announcements which merit special attention. The way corporate events affect stock returns depends on their type including bonus issues, rights offer, stock splits, revenue releases, dividend payments, mergers, acquisitions, and share repurchases.

Studies find that stock market reaction to company news differs across business sectors. Research analyzes the impact of corporate events on stock returns by examining whether investors earn abnormal returns both before and after event announcements. Academicians Ball and Brown (1968) first established the "event study" technique which serves as the foundation of this research.

Several measures are commonly used in event study methodology to assess the impact of corporate event announcements: Investors use CAAR to measure stock performance alongside BHAR and existing market performance as WR. The CAAR tool tracks immediate trading responses yet BHAR and WR reveal persistent market impacts over time. Stock market reactions to announcement display quick shifts (short-term impact) over several days or weeks followed by sustained adjustments over several months (long-term impact).

To determine expected returns CAAR uses different asset pricing models. Stock valuation models predict returns by factoring in enterprise criteria together with economic elements. A common practice in stock market analysis depends on the Market Model as its single-index model. Research teams created updated models after 1964 which added elements from the Capital Asset Pricing Model (CAPM) (Sharpe, Lintner, Mossin) plus research by Fama, French, Carhart, Fama-French, and Fama-French.

Multiple studies now explore the quick effects that corporate event updates have on shareholder money using event study approaches and contrast how two corporate events affect stock values at once. Research in Sri Lanka lacks comprehensive analyses on the relation of stock dividend announcements to stock returns and it lacks studies comparing four corporate events' returns impacts across industry sectors. Sri Lankan researchers study short-term stock market effects of corporate events using only the Market Model in event methods.

When the Market Model arrived in 1960s it represented a single-index solution that overlooked key firm and macroeconomic influences. Advanced asset pricing models including the CAPM help explain stock return drivers better than use of simple market model. Our research community requires new studies that examine how various asset pricing theories produce expected returns when used in event study evaluation in Sri Lanka.

A. Literature Review

A business adopts corporate actions to manage its financial arrangement while improving market value and performance. Business actions produce vital market results by influencing how investors think about stocks. Both past and present research studies support the strong stock market impact that corporate announcements produce. Recent research findings show that most corporate announcements either improve performance or maintain positvity while some investigations point to negative returns. This section reviews and examines published research that studies different corporate announcements and their effects on stock prices and returns.

2.1 Impact of Right Issue Announcement

Because existing shareholders receive discounted share offers in right issues analysts closely study this practice to determine its stock price effects. Levy, Haim, and Samat [1971] studied stock price changes when companies made public right issue announcements according to AliSabri et al. (2004). The research showed price fluctuations at right issue announcements stemmed mostly from the impact on future dividend predictions instead of the announcement itself. Right issue announcements produced erratic cost impact for investors that did not affect their stock returns.

Research teams including Scholes (1972) and White and Lusztig (1980) showed stock prices fell after companies announced right issue programs. Studies from Asquith and Mullins (1986) and Kit [1990 as cited in AliSabri et al. (2004)] reached similar results. The studies revealed price drops after announcement events yet Scholes and Asquith recognized lasting decrease while White's team found short-lived market impacts.

Ramesh and Rajumesh (2014) conducted a standard event study to assess the right issue impact on stock performance in their research. They tracked Abnormal Returns (AR) during the study period to reveal Average Abnormal Returns (AAR) and Cumulative Average Abnormal Returns (CAAR). According to the research findings, the stock returns of shareholders experienced a positive impact of 1.54% on their investments immediately after the CSE right issue announcement.

2.2. A bonus issue proclamation revealed its results.

This research compares how stock prices react to bonus issue announcements when companies distribute free shares to shareholders. During 2005 Balachandiran studied the stock market reaction in Australian companies following bonus issue announcements. His research showed market-linked statistical evidence that stock prices grew by an average 2.37% when no error occurred and 2.11% when errors were present on the day of the announcement and the following day.

According to Dhar and Chhaochharia from 2008 they examined the market impact of bonus issues and stock splits on NSE-listed firms through event study analysis. Studies show bonus issues produce 1.8% positive stock returns while stock splits create 0.8% growth in stock price over short-term periods.

Through standard event testing Raja and Clement Sudhahar (2010) studied BSE IT company bonus issue news to measure market response in Indian capital markets. The research identified large positive Abnormal Returns at announcement time and throughout the next several days with Combined Average Abnormal Returns spiking from -2.11 to 17.16 by day two after the announcement. When companies announced bonus issues the market responded rapidly by boosting stock prices.

Ramesh and Nimalathasan (2011) studied how investors reacted to bonus issues in the CSE market during the period before formal announcements. Share prices showed greater market response before the official announcement than throughout or after the event took place. The study found evidence that information leaked earlier on which damaged Colombo Stock Market operations.

2.3. The Market Reaction to a Company's Public Declaration of its Stock Split Action

Research shows that analysts study stock split steps that companies take to make stocks more affordable for investors. Wolff (2002) determined German companies experienced positive investment gains when their executives announced stock splits and when splits finally took effect. His findings showed stock prices became more volatile after companies split their shares.

Grinblatt Masulis Titman's 1984 study in Gunnathilaka et al. (2009) shows stock splits boost prices when they demonstrate better liquidity and invite new investors. Amihud and Mendelson pointed out in 1986 (cited by Gunathilake et al. in 2011) that companies can use stock splits to communicate better financial liquidity performance.

According to Rajesh (2013), the Indian market demonstrated no reaction to stock split news both before and after the announcements when measured through event windows and market models. In 1999 Abeyaratna, Bandara, and Colombage evaluated the semi-strong market efficiency at the CSE using Granger causality tests. They showed stock split announcements created market reactions across sectors yet financial and manufacturing businesses did not change. Research by Gunathilake (2011) showed Sri Lankan stock markets reacted positively to stock split news by adjusting stock returns and having more trades on the day of disclosure.

2.4. The financial industry responds to information about stock dividend programs

Research shows that when companies pay dividends through new stock shares they impact stock market reactions. Based on New York Stock Exchange data from 1959 Barker discovered stock dividends lacked an impact on share price but benefited trading volume and market demand.

Adaoglu and Lasfer (2011) showed that markets reacted favorably to stock dividend news most strongly with financially weak companies yet less strongly with stronger companies. A study by Chavali and Nusratunnisa (2013) using 67 FMCG firms showed stock dividends positively impacted company returns and market value except when outside forces limited their effectiveness.

In 2002 Bandara and Samarakoon analyzed how cash dividend news affects Sri Lankan companies. Smaller companies and those who declared high dividend growth received pronounced market reactions according to their studies. Research showed investors in emerging markets start making decisions before company news is released.

Ramesh conducted research in 2012 on Sri Lanka's CSE by studying how manufacturers and non-manufacturers reacted to dividend news. His data showed strong positive stock return changes when dividend payments started on that day because investors obtained useful dividend information from Sri Lankan companies.

B. Methodology

The study consists of all the companies listed on the Colombo Stock Exchange (CSE) representing 17 business sectors, excluding the banking sector and diversified financial sector insurance sector, due to the differences in reporting methods and capital structure as of 31st December 2019. The study's sample period is from 2017 to 2021. To find the current market situation of Sri Lanka, the year 2017-2021 is taken as a sample period.

Each event is analyzed separately for the study. For every event, the abnormal return in the price of all the sample firms will be computed for the days preceding and following the announcement day. There are 13 Stock dividends, 9 bonus issues, 31 right issues, and 29 stock splits event announcements throughout the study period. (Table 1& 2).

To determine the expected return, the study is expected to use event study analysis together with a market model as the asset pricing model. However, the researcher will follow the subsequent steps to analyze the impact of corporate event announcements on stock returns. To begin with, the research period's event date—that is, the date on which corporate events are announced—is decided for every company that met the requirements and was chosen. This day is called "Day Zero". Second, the event window is determined, and it is determined to be an event window from -10 to +10 (ten days before the event date, "day zero", and ten days after). It is in line with many other event studies by Ramesh and Nimalathasan (2011), Gunasekara (2004), and Baharuddin and Teoh C Ying (2010). Third, the calculation of the daily return for the company's stock in the study years is estimated by the following equation:

$$Rit = LN(Pit/Pit\text{-}1) \quad (1)$$

- Rit = the actual return of the company stock i on the day t,
- Pit = closing price of the company's stock i at the end of the day t,
- Pit -1 = closing price of the company's stock i at the day t -1

Fourth, the expected return per stock for each company is calculated.

The Market Model & Quant:

$$E(Rit) + \beta i(Rmit) + \varepsilon i \quad (2.1)$$

The asset pricing models work under the assumption that $\boldsymbol{\varepsilon i}$ has an expected value of zero and is unrelated to the market as a whole.

E(Rit)=Expected Return of Investment

Rmit = The rate of return on the market on day't'/ The Market Index's Return

αi = The return from the asset unrelated to the market's return.

βi = Slope of a straight line (beta coefficient) of stock i

εi = Error term for past returns not explained by the regression equation.

Over a 200-day estimation period, from day t-210 to day t-10, the market model's parameters were calculated. This 200-day duration falls within Strong's suggested range (1992). Market portfolio return will be proxied by the ASPI Index; Risk-free rate will be proxied by Treasury bill rates. The market capitalization of each company will be taken from the CSE data library on the 31st of December each year. Book Value of Equity (BV), Operating income, and Total Asset value will be taken from the company's annual report on the 31st of December each year.

Fifth, the study will have the actual return from the CSE Library and the expected return of the companies from the data set and equation (2). The next step is determining the abnormal return via equation (3); the study will have five (5) abnormal returns for each corporate event announcement.

$$A(Rit) = Rit - E(Rit) \quad (3)$$

Where:

ARit = the abnormal return on day t.

Rit= the actual return on the day t.

E (Rit) = the expected return on the day t: from equation (2).

The average abnormal return (AAR) will be calculated by averaging the abnormal returns of each stocks for each day in the event window before and after the event day. To remove the company-specific impact on information release, the abnormal return for each day is averaged over all the companies in the data set.

$$AAR = \Sigma\, ARit * 1/N \quad (4)$$

Sixth, the Cumulative Average Abnormal Return (CAAR) for every day in the study window period. The CAAR will be determined using the formula.

$$CAAR = \sum n\, AARit \quad (5)$$

Hence, the study has twenty-one (21) views for CAAR, depending on the number of window days.

Seventh, the test of the Research Hypothesis.

Hypothesis 01:

H01: There is no significant relationship between the Scrip dividend announcement and the Stock returns.

H02: There is no significant relationship between the Bonus Issue announcement and the Stock returns

H03: There is no significant relationship between Right Issue announcement and the Stock returns

H04: There is no significant relationship between Stock split announcement and the Stock returns

Hypothesis 02:
H1a: The CAAR around the event date is not different to the zero

C. Results and Discussion

The right issue demonstrates that there is a positive and negative fluctuation yield in the value of AARs and CAARs. This makes it obvious that the day of the appropriate problem statement (Day 11=Day 0) is when negative major CAARs are earned. The market always sees right issue announcements as bad news for a company's future direction. After bonus issue announcements the market shows both positive and negative movements in average abnormal returns and cumulative averages before and after event day. Soon after CAAR grows from its bonus issue announcement it decreases while AAR shows consistent slow reductions. The event day shows positive and negative significant CAAR changes. Companies receiving bonus issues face a negative market perception about their upcoming direction. After an event day stock dividends show small but changing CAAR and AAR results. When stock dividends are announced there is a clear upward shift in both AAR and CAAR figures over a few days. The reported CAAR values on event day zero show both positive and negative patterns. The market reacts positively to stock dividend announcements because they indicate high future company expectations. After the news break companies experience steady growth in their daily stock earning numbers. After stock splits AARs and CAARs display small changes that move between positive and negative values across different time periods. The indexes CAAR and AAR rise after the news of a stock split but CAAR dips slightly at first before coming back up. Though CAAR decreases first it starts to grow steadily which brings negative returns back to zero.

D. Descriptive Statistics

The table represents the descriptive statistics for cumulative average abnormal return for each announcement within the event period. The mean value, median, standard deviation, skewness minimum and maximum value for each announcement are included below. (see Table 3)

E. CAAR and AAR Analysis

Used a two-sided t-test to investigate the daily and complete event period abnormal returns of the studied companies. Using 82 events from Sri Lankan companies between 2017 and 2021 the study analyzed how well investors were informed when companies issued right issue, stock dividend, stock split, and bonus stock announcements across multiple developing market sectors listed on CSE. Our analysis showed returns above normal levels throughout the evaluation window for all types of announcements.

Right issue announcements on the event day produced an average abnormal return of -7.45% which failed to reach statistical significance by a t-value of 0.7892. On event days' public markets react slowly at best to right issue disclosures. During the (0 to +10) period the market generated 2% excess average earnings compared to regular gains. Our findings show minimal market responsiveness following right issue announcements which confirms defects in both how information spreads and reaches investors. The slow market reaction to these companies' disclosures suggests internal market problems. Across all industries the market showed no reaction to new share offerings at the time of announcement according to this research.

The test results show a statistically insignificant decline in stock value (-1.36%) at the 5% level when companies announced stock dividends (Table 5). The market does not show immediate response to stock dividend disclosures made by companies on their event day. During these ten days the total average return difference totaled 10%. The study found that stock dividend announcements throughout all industries created no abnormal return on the event day.

During stock split announcement days an average return of -30.47% showed no significant market reaction (t=-1.2759). The market showed no immediate reaction when companies announced stock splits on the event day. During the time window from zero to plus ten days the aggregate abnormal returns generated a negative return of three percent. Our findings showed that the CAAR for stock split news arrived across different sectors did not turn out to be zero.

The average abnormal return of bonus issue announcements measured 1.84% on the event day but this result was not statistically meaningful (t = 1.2277) at the 5% level. The market showed only slow response to bonus issue news on the day of distribution. During our study period of 10 days after the market announcement we registered a small yet measurable return of 0.08% on average. This research found bonus issue announcements for all industries generated zero total market reaction on event day.

The results demonstrate that markets process information about stock returns slowly and inconsistently in the different industry groups. Please tell me if you want me to extend or enhance these findings. (See Table 4/5/6 /7)

F. Figures and Tables

TABLE 1 - Number of Corporate Event Announcements for the period of 2017-2021

Event	2017	2018	2019	2020	2021	Total
Stock Dividend	2	2	4	2	3	13
Bonus Issue	4	4	0	0	1	9
Right Issue	3	8	7	8	5	31
Stock Split	2	2	1	1	23	29

TABLE 2 - Number of Corporate Events Announcements in each sector

Stock Dividend	**2017**	**2018**	**2019**	**2020**	**2021**
Consumer Services	1	1	-	-	-
Capital Goods	-	-	1	1	1
Utilities	-	-	1	1	1
Real Estate	-	-	-	-	1
Food Beverage and Tobacco	1	1	2	-	-
Total	2	2	4	2	3
Bonus Issue	**2017**	**2018**	**2019**	**2020**	**2021**
Utilities	1	-	-	-	-
Materials	1	-	-	-	-
Consumer Services	1	-	--	-	-
Consumer Durables & Apparel	-	1	-	-	-
Food Beverage & Tobacco	1	-	-	-	-
Food & Staples Retailing	-	2	-	-	-
Retailing	-	-	-	-	1
Real Estate	-	1	-	-	-
Total	4	4	0	0	1

Right Issue	**2017**	**2018**	**2019**	**2020**	**2021**
Capital Goods		3	1	2	2
Consumer Services			4	2	1
Real Estate	1	2	2	1	
Materials				1	
Food Beverage & Tobacco	1	1		2	1
Household & Personal Products	1	-		-	-
Retailing		1	-		-
Trading		1			
Utilities					1
Total	3	8	7	8	6
Stock Split	**2017**	**2018**	**2019**	**2020**	**2021**
Capital Goods			-	1	7
Consumer services					2
Consumer Durables & Apparel					4
Retailing	1			-	1
Materials	-		-	-	6
Real Estate	1	-	1	-	
Food Beverage & Tobacco	-	2	-		3
Total	2	2	1	1	23

TABLE 3 – Descriptive Statistics

	Right Issues	**Stock Dividends**	**Stock Split**	**Bonus Issue**
Mean	0.02492	-0.11101	0.02583	-0.00310
Std. Error of Mean	0.02027	0.01602	0.05734	0.00259
Median	0.02312	-0.11765	-0.03983	-0.00559
Std. Deviation	0.09291	0.07342	0.26274	0.01188
Skewness	0.01318	0.31660	0.20501	0.79604
Kurtosis	-1.31897	-1.22911	-0.91108	-0.15039
Minimum	-0.12315	-0.21296	-0.40254	-0.02027
Maximum	0.16702	0.00632	0.50453	0.02115

TABLE 4 – Right Issue announcement

Event Date	**AAR**	**CAAR**	**t-stat**	**Sig. value**
-10	0.0231	0.0231	1.8657	0.0719
-9	0.0236	0.0467	1.9361	0.0623
-8	0.0182	0.0649	1.8474	0.0746
-7	0.0168	0.0817	1.8741	0.0707
-6	0.0191	0.1007	1.9044	0.0665
-5	0.0191	0.1198	1.9389	0.0620
-4	0.0214	0.1412	1.9407	0.0617
-3	0.0153	0.1565	1.8976	0.0674
-2	0.0105	0.1670	1.7966	0.0825
-1	-0.0240	0.1430	1.5913	0.1220
0	-0.0745	0.0686	0.7892	0.4362
1	-0.0784	-0.0098	-0.0858	0.9322
2	-0.0434	-0.0532	-0.3954	0.6953
3	-0.0326	-0.0859	-0.7090	0.4838
4	-0.0217	-0.1076	-1.0826	0.2876
5	-0.0156	-0.1231	-1.4694	0.1521
6	0.0389	-0.0842	-1.4702	0.1519
7	0.0220	-0.0622	-1.6892	0.1016
8	0.0250	-0.0372	-1.5666	0.1277
9	0.0102	-0.0270	-1.8539	0.0736
10	0.0274	0.0004	0.0992	0.9217

Null Hypothesis	**Sig.**	**Decision**
The t0 equals to 0.000	0.347	Not Rejected

TABLE 5 – Stock Dividend Announcement

Event Date	**AAR**	**CAAR**	**t-stat**	**Sig. value**
-10	0.0044	0.0044	0.3057	0.7668
-9	0.0019	0.0063	0.2276	0.8251
-8	-0.0054	0.0009	0.0239	0.9815
-7	-0.0165	-0.0156	-0.3401	0.7416
-6	-0.0297	-0.0453	-0.8496	0.4176
-5	-0.0282	-0.0735	-1.1627	0.2749
-4	-0.0192	-0.0927	-1.2284	0.2504
-3	-0.0064	-0.0991	-1.1492	0.2801
-2	-0.0076	-0.1067	-1.0932	0.3027
-1	-0.0110	-0.1176	-1.0854	0.3060
0	-0.0136	-0.1312	-1.0968	0.3012
1	-0.0169	-0.1482	-1.1314	0.2871
2	-0.0145	-0.1627	-1.1318	0.2870
3	-0.0180	-0.1807	-1.1308	0.2874
4	-0.0045	-0.1851	-1.0831	0.3069
5	-0.0054	-0.1905	-1.0575	0.3178
6	-0.0014	-0.1919	-1.0353	0.3276
7	-0.0113	-0.2032	-1.0411	0.3250
8	-0.0098	-0.2130	-1.0331	0.3285
9	0.0671	-0.1459	-1.0320	0.3290
10	0.1058	-0.0401	-1.0427	0.3243

Null Hypothesis	**Sig.**	**Decision**
The t0 equals to 0.000	0.203	Not Rejected

TABLE 6 – Stock Split Announcement

Event Date	**AAR**	**CAAR**	**t-stat**	**Sig. value**
-10	0.0583	0.0583	6.5398	0.0000
-9	0.0584	0.1167	6.6471	0.0000
-8	0.0059	0.1227	1.9674	0.0591
-7	0.0688	0.1915	2.6588	0.0128
-6	0.0610	0.2525	3.2331	0.0031
-5	0.0654	0.3179	3.7568	0.0008
-4	0.0584	0.3763	4.3774	0.0002
-3	0.0681	0.4445	4.8982	0.0000
-2	0.0601	0.5045	5.3035	0.0000
-1	-0.3041	0.2005	2.5773	0.0155
0	-0.3047	-0.1043	-1.2759	0.2125
1	-0.2983	-0.4025	-3.7968	0.0007
2	0.0568	-0.3457	-3.2744	0.0028
3	0.0495	-0.2962	-2.7632	0.0100
4	0.0468	-0.2494	-2.2996	0.0291
5	0.0629	-0.1865	-1.7300	0.0946
6	0.0343	-0.1522	-1.5917	0.1227
7	0.0359	-0.1163	-1.2796	0.2112
8	0.0246	-0.0917	-0.9897	0.3308
9	0.0334	-0.0582	-0.7930	0.4344
10	0.0184	-0.0398	-0.7305	0.4712

Null Hypothesis	**Sig.**	**Decision**
The t0 equals to 0.000	0.001	Rejected

TABLE 7 – Bonus Issue Announcement

Event Date	**AAR**	**CAAR**	**t-stat**	**Sig. value**
-10	-0.0025	-0.0025	-1.0033	0.3451
-9	-0.0039	-0.0064	-1.2864	0.2343
-8	-0.0064	-0.0128	-1.6313	0.1415
-7	-0.0028	-0.0156	-1.5585	0.1577
-6	0.0018	-0.0137	-1.3139	0.2253
-5	-0.0008	-0.0146	-1.5282	0.1650
-4	0.0000	-0.0146	-1.5717	0.1547
-3	-0.0056	-0.0203	-1.8733	0.0979
-2	0.0096	-0.0107	-0.7187	0.4928
-1	0.0114	0.0006	0.0429	0.9668
0	0.0184	0.0191	1.2277	0.2544
1	0.0021	0.0211	1.5695	0.1552
2	-0.0029	0.0182	1.4403	0.1877
3	-0.0095	0.0088	0.7411	0.4798
4	-0.0038	0.0049	0.5259	0.6132
5	-0.0048	0.0001	0.0162	0.9875
6	-0.0037	-0.0036	-0.4849	0.6408
7	-0.0052	-0.0088	-1.1665	0.2770
8	0.0007	-0.0080	-1.2451	0.2483
9	0.0024	-0.0056	-1.2336	0.2524
10	0.0048	-0.0008	-1.1715	0.2751

Null Hypothesis	**Sig.**	**Decision**
The t0 equals to 0.000	0.441	Not Rejected

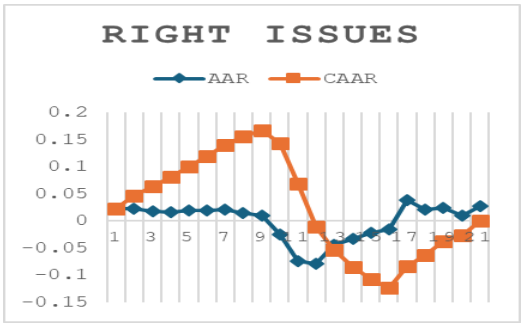

Fig. 1. Right Issue

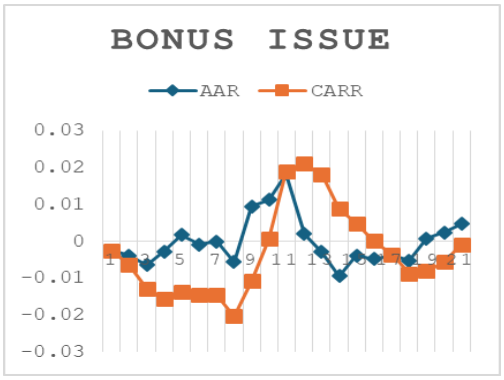

Fig. 2. Bonus Issue

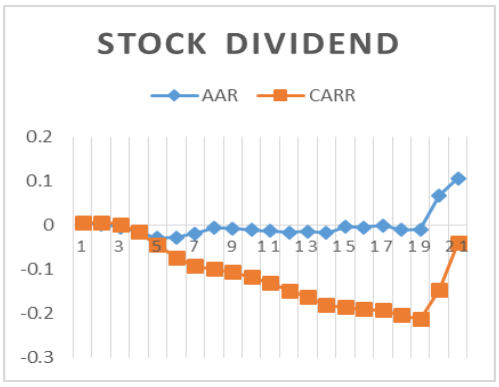

Fig. 3. Stock Dividend

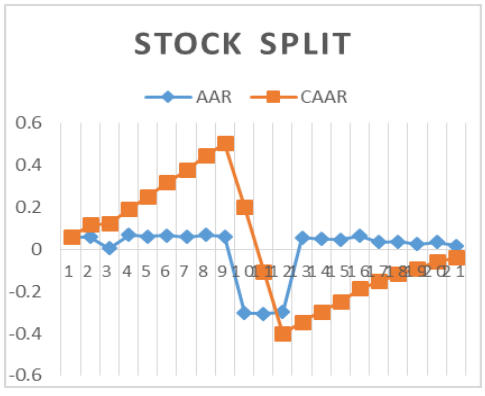

Fig. 4. Stock Split

II. Conclusion

An economy's foundation depends on marketplaces for capital distribution so they need to work smoothly. According to Malkiel (2010) national economic growth benefits from competitive financial market operations. The financial market uses security prices to track market trends. Research reveals conflicting opinions about market efficiency across different types of announcements in the Sri Lankan capital market.

This study analyzed four major announcements in Sri Lanka: Our research focuses on four main market events: right issue, stock dividend, stock split, and bonus issue. The research team analyzed the stock market movements following official releases through standard event methods. The market showed no noticeable changes during the event periods. The stock market analyzed all available event information during Day "0" which demonstrated that investors needed time to comprehend the announcement data. The measurements from event day results showed no relevant statistical differences at a 5% significance level.

Following right issue announcements investors earned 0.3% above-average returns five days later. During the 21-day observation period following the event day market participants experienced favorable average abnormal returns (AARs) in two-thirds of cases combined with negative results in one-third of cases. The period before (-10 to -1) right-issue announcements triggered a boost in stock performance that gave investors 14.30% returns. After (0 to +10) investors earned minimal returns of 0.04%. Research reveals a future opportunity for above-average returns from this information delay.

After receiving stock dividend news shareholders achieved positive returns of 0.9% on day eight. During the 21-day window period our research showed 81% of cases had unfavorable AARs before event day but 19% produced positive results. The period ten days prior up to the day before the announcement revealed a negative change in shareholder wealth at 11.76%. After the announcement shareholders did not show noticeable changes in their wealth during the next ten-day period.

When companies announce stock splits shareholders typically see returns rise 5.7% the following day. During the 21-day period that precedes the event date shareholders saw positive AAR results in 86% and negative AAR situations in just 14%. Prior to the disclosure (-10, -1) investors reacted positively with a 20% Capital Accumulation and Appraisal Response while the market showed little reaction following announcements during (0, +10) with -4% CAAR.

When companies declared bonus issues shareholders received a positive 0.2% market return on the event day before experiencing negative returns from day eight onward. The study repeated positive results of 0.0007 through subsequent observations. For 43% of the examples during the 21-day window period investors received positive AAR results while 57% saw negative AAR results because the forecasts before the event day failed. From 11 days before to 1 day before the event investors showed a 0.06% decline in market value while shares posted -0.08% loss during 10 days afterwards.

The study focused on companies traded on the CSE across 17 business sectors except banking which had unique financial reporting practices. The analysis was restricted to four announcement types: This study researched scrip dividend, bonus issue, right issue and stock split announcements. Both global economic conditions and trading expenses were omitted from our analysis of investment performance during the chosen time period.

Additional studies must examine how other financial company events impact stock performance of CSE-listed firms. Research focused on only eleven years from 2008 through 2019.

REFERENCES

[1] Akbas, F., Armstrong, W. J, Sorescu, S., & Subrahmanyam, A. (2014). Capital Market Efficiency and Arbitrage Efficacy.

[2] Anderson-Weir, C. H. (2010). How Does the Stock Market React to Corporate Environmental News? Undergraduate Economic Review, 6(1).

[3] Ball, R. (2009). The Global Financial Crisis and the Efficient Market Hypothesis: What Have We Learned? Journal of Applied Corporate Finance, 21(4), 8-16.

[4] Bandara, D., and Samarakoon, P. (2002). Dividend Announcements, Firm Size and Dividend Growth in the Sri Lankan Stock Market. Sri Lankan Journal of Management, 7(3), 228-245.

[5] Barone, E. (1989). The Italian Stock Market: Efficiency and Calendar Anomalies. http://dx.doi.org/10.2139/ssrn.512503

[6] Bechev, I. (2011). Efficient Market Hypothesis: Budapest, Prague and Warsaw Stock Exchange. SSRN Electronic Journal, 1-33. https://doi.org/10.2139/ssrn.625901

[7] Chavali, K., & Zahid, Z. (2001). Impact of Stock Splits on Stock Price Performance of Selected Companies in Indian Context. Afro-Asian Journal of Finance and Accounting, 2(3), 270-282. https://doi.org/10.1504/AAJFA.2011.041633

[8] Dasilas, A., & Leventis, S. (2011). Stock Market Reaction to Dividend Announcements: Evidence from Greek Stock Market. International Review of Economics and Finance, 20(2), 302-311. https://doi.org/10.1016/j.iref.2010.06.003

[9] Degutis, A., & Novickte, L. (2014). The Efficient Market Hypothesis: A Critical Review of Literature and Methodology. Working Paper.

[10] Dhar, S., & Chhaochharia, S. (2011). Market Reaction Around the Stock Splits and Bonus Issues: Some Indian Evidence. SSRN Electronic Journal, 9434139726(M), 1-24. https://doi.org/10.2139/ssrn.1087200

[11] Dragota, V., Opera, D., & Brasoveanu, L. O. (2019). Market Efficiency, Prediction and Returns. Economic Computation and Economic Cybernetics Studies and Research, 53(3), 59-76.

[12] Fama, E., & French, K R. (2000). Disappearing Dividends: Changing Firm Characteristics or Lower Propensity to Pay? AFA 2001 New Orleans; CRSP Working Paper No. 509. http://dx.doi.org/10.2139/ssrn.203092

[13] Fama, E., Fisher, L., Jensen, M., & Roll, R. (1969). The Adjustment of Stock Prices to New Information. International Economic Review, 10(1), 1-21. https://doi.org/10.2307/2525569

[14] Griffin, J. M., Kelly, P. J., & Nardari, F. (2011). Are Emerging Markets More Profitable? Implications for Comparing Weak and Semi-Strong Form Efficiency. SSRN Electronic Journal. https://doi.org/10.2139/ssrn.959006

[15] Gunalp, B., Kadioglu, E., &Killc, S. (2011). The Announcement Effect of Cash Dividend on Share Prices and the Tax Clientele Effect: Evidence from Turkish Capital Markets. Euro Conference 2011: Crises and Recovery in Emerging Markets.

[16] Guo, S., & Wang, Z. (2007). Market efficiency anomalies A study of seasonality effect on the Chinese stock exchange (pp. 1-64).

[17] Gupta, S., Dogra, B., Vashisht, A. K., & Ghai, S. (2012). Stock Price Reactions to Dividend Announcements. International Journal of Management, 2(2), 23-31.

[18] Hua, B. L., & Ramesh, S. (2013). A Study on Stock Split Announcements and its Impact on Stock Prices in Colombo Stock Exchange (CSE) of Sri Lanka. Global Journal of Management and Business Research Finance, 13(6), 25-34.

[19] Jarrow, R. A., & Larsson, M. (2011). The Meaning of Market Efficiency. Johnson School Research Paper Series No. 07-2011. http://dx.doi.org/10.2139/ssrn.1781091

[20] Kulakarni, V., & Chandani, A (2020). A Study to Analyse Effect of Corporate Actions on Stock Market Returns of Selected Indian IT Companies. e-journal-First Pan IIT International Management Conference – 2018.

[21] Kumar, H., & Jawa, R. (2017). Efficient Market Hypothesis and Calendar Effects: Empirical Evidences from the Indian Stock Markets. Business Analyst, 37(2), 145-160.

[22] Lakshmi, V., & Roy, B. (2012). Price Earnings Ratio Effect: A Test of the Semi Strong Form of Efficient Market Hypothesis in Indian Stock Market, XI Capital Markets Conference, 21-22 December 2012, Indian Institute of Capital Markets (UTIICM). https://dx.doi.org/10.2139/ssrn.2255389

[23] Los, C A. (2004). Measuring the Degree of Financial Market Efficiency: An Essay. https://dx.doi.org/10.2139/ssrn.614544

[24] Malkiel, B. G. (2010). Bubbles in Asset Prices. CEPS Working Paper No. 200.

[25] Marisetty, N., & Babu, S. (2017). Corporate (Dividend) Actions and Impact on Stock Abnormal Returns: A Study on Indian Context. International Journal of Management and Social Sciences Research, 6(11), 30-35.

[26] Marisetty, N., & Babu, S. (2018). Impact of Corporate Action (different Stock Split Ratios) on Stock Price in India. International Journal of Research in Economics and Social Sciences, 8(1), 205-213.

[27] Marisetty, N., & Pasha, A (2017). a Study on the Impact of Dividend on Stock Prices. International Journal of Management Studies, 4(1), 1-9.

[28] Mishra, A. K. (2005). An Empirical Analysis of Market Reaction around the Bonus Issues in India. IIML Working Paper Series No: 2005-10.

[29] Nishanthini A.& Nimalathasan B. (2014). Market Efficiency and Its Impact on Share Price: A Study of Listed Manufacturing Companies in Sri Lanka. Asia Pacific Journal of Research, I(XX), 111-120.

[30] Rao, K. K. (2014). Corporate Actions and Impact on Stock Prices – An Empirical Study of Indian Markets. Galaxy International Interdisciplinary Research Journal, 2(1).

[31] Rozeff, M. S., & Zaman, M. A. (1988). Market Efficiency and Insider Trading: New Evidence. In The Journal of Business, 61(1), 25. https://doi.org/10.1086/296418

[32] Shirur, S. (2008). Dilemma of Corporate Action: Empirical Evidences of Bonus Issue vs. stock Split. Vikalpa, 33(3), 35-47. https://doi.org/10.1177/0256090920080303

[33] Titan, A. G. (2015). The Efficient Market Hypothesis: Review of Specialized Literature and Empirical Research. Procedia Economics and Finance, 32(15), 442-449. https://doi.org/10.1016/s2212-5671(15)01416-1

[34] Venkatesan, T., & Nagaraj, R (2018). Analysis of Corporate Actions and Market Efficiency in India. SJCC Management Research Review, 8(1), 75-89.

Sentiment Analysis for Amazon Reviews to Identify Customer Interests

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Abstract— Online shopping has become a routine activity in the 21st century, with customers relying on reviews to assess product quality. Companies also analyze these reviews to improve their services. This research applies sentiment analysis to Amazon product reviews to extract business insights from large datasets. LDA model is developed for the Amazon review dataset to identify the narrowed down topics which the entire collection of reviews is based on. We provide visualization of word frequencies in each topic. The sentiment analysis is conducted per topic basis after identifying which machine learning model is best suited to the sentiment analysis. The topics obtained from the LDA model are classified using logistic regression as positive or negative product review topic. The positive and negative topics are analyzed to provide a business insight on the product specially taking the negative reviews into attention. This research can be applicable to all online businesses which constantly receive online reviews.

Index Terms— Voice of Customer, Natural Language Processing, Information Retrieval, Machine Learning, Human-Computer Interaction, Bag of Words, Part of Speech, Natural Language Tool Kit, Latent Dirichlet Allocation

I. Introduction

Online shopping has immensely grown through the past decade as no one has ever predicted and imagined. In online shopping systems, customers don't rely on word-of-mouth recommendations further they lean toward a review received for the product that they intend to buy [1]. According to IGI Global, an online review evaluation is produced by the consumer for a certain online product or service that has been experienced by them [2]. However, that is not the only use of these reviews; they are also used to conduct statistical analyses to derive customer behavior after a product or a service is purchased, which will help development plans for the business for its growth [3].

Statistics indicate the importance of online reviews. According to Fan & Fuel (2016), 94% of online customers read reviews before deciding on a purchase. Especially when it is product-specific information, Spiegel Research Centre (2017) shows that 95% of customers read reviews prior to purchase. These statistics give a clear understanding that the availability of the product or the service is not adequate; customers want the knowledge from first-hand experiences [3][4].

Sentiment analysis typically analyses the emotion that's expressed in a text content. It is not only used in customer reviews for a product as above mentioned, it is also used in survey response analyzing, feedback for a product or service provided, or even a comment on a social media site. This has been used in various sectors, especially in business applications to make sense of qualitative data. Such business applications are Voice of Customer (VoC) Programs, Customer Service Experience, Social Media Sentiment Analysis, Product Experience, Brand Sentiment Analysis, Market Research, etc. [5]. Through mere human reading of reviews, it is difficult to understand the customer base for a product, the product's market reach, type of audience, customer pattern, as well as customer hidden interest which are valuable insights for the product.

Use Machine Learning Techniques to analyze the data lake as a result acquire deep insights toward the products [8]. This research emphasizes the importance of customer reviews as a source of information to dig deep into customer opinions and their further interests. The study is conducted in two aspects. First, a comprehensive statistical analysis of a publicly available dataset containing various Amazon Alexa reviews. The dataset is available at the following citation [9]. Secondly, a sentiment analysis allowing large-scale processing of data to these Amazon reviews in an efficient and cost-effective manner [12].

Latent Dirichlet Allocation (LDA) was selected as the topic modeling technique due to its effectiveness in identifying underlying thematic structures within large, unstructured datasets like customer reviews. LDA is particularly valuable for this study as it offers interpretability and helps uncover distinct topics, allowing businesses to better understand common customer concerns and preferences. Prior to applying the LDA model, several preprocessing steps were conducted to ensure data quality and relevance. This included removing noise (such as irrelevant words or special characters), handling duplicates to prevent data skewing, and filtering out reviews that did not provide meaningful feedback. These steps enhance the rigor of the analysis by ensuring that the dataset used is clean and representative, ultimately providing more accurate insights from the sentiment analysis. In the objectives methodology expected to use time frame for the research events and lastly the reference will be discussed in order.

II. Related work

Sentiment is defined as a thought, attitude, or judgment triggered by a feeling. Sentiment analysis is basically a study on human sentiment on a subject area; much more simply it could be described as an attitude towards something [10][11]. Sentiment analysis is also known as opinion analysis. People have found it extremely easy to express their opinion with the vast popularity of the Internet. Viewers and users can review, comment, provide feedback on the purchased products, different social media sites, filling out forms and forums, etc. Through these massive data collections through online platforms, sentiment analysis has developed the basic fundamentals properly. However, these online data have created several flaws in the process of sentiment analysis. First identified flaw is since anyone can publish the content on the internet, the online text gathered would not be highly guaranteed. Some reviews can be considered and there are others that may be considered as fake opinions. Secondly, identified drawback is when the data is presented, the real classification also known as the ground truth is not provided with it. Which indicates whether the review is really positive or negative [12].Sentiment analysis uses various technical concerns in its proceedings such as natural language processing, text analysis, and computational linguistics to recognize and extricate information on the subjectivity of the content [13]. Sentiment analysis is used widely in modern industries from marketing business aspects to customer care provided. The main intention of sentiment analysis is to identify the writer's perspective and opinion and evaluate those parameters according to a single topic domain or multiple topic domains. Currently, there are four main types of sentiment analysis conducted: entity level, word level, sentence level, and document level [14].

Sentiment analysis consists of many technical concepts such as natural language processing (NLP) and machine learning (ML) algorithms. Simply how sentiment works is a model is trained on millions of text chunks to detect if a message is positive, negative, or neutral [15].

In this approach, we construct a unit in a language called lexicon with the information on which words, expressions, or phrases have positive and which have negative meanings. As an example, SentiWordNet is a lexical resource used in each WordNet. Synset provide three numerical scores on the objective, positive, and negative on each lexicon [16].

Fig. 1: Sentiment analysis workflow

During the past two years with the COVID-19 pandemic, online shopping and online buying user percentage grew drastically, almost over one hundred percent. Similarly, the percentage of Internet users has exponentially grown and it will be continuing this pattern in the future [18]. The 2011 study shows it is 74% of customers trust the recommendations, but it declined in 2012 and 2013 to 60% and 57% respectively. However, the results have changed in 2019 which shows an increment of up to 94% of customers who have faith in online sentiment reviews [19].

In addition to sentiment analysis, topic modeling methods like Latent Dirichlet Allocation (LDA) have been employed to identify hidden topics within customer reviews. LDA has been instrumental in classifying and organizing text corpora based on themes, helping businesses extract valuable insights from large-scale unstructured data. While sentiment analysis has made significant strides, challenges such as detecting sarcasm and processing domain-specific language remain areas of active research [18]. In addition to LDA, other topic modeling techniques, such as Non-Negative Matrix Factorization (NMF) and BERT-based models, have been explored in similar studies for organizing and classifying textual data. While methods like BERT are effective for capturing contextual relationships in text, LDA remains advantageous in its interpretability and efficiency for identifying overarching themes within large datasets, making it suitable for this study. Furthermore, ethical considerations such as data anonymization and compliance with data privacy standards are crucial when handling customer review data. These measures are essential to protect individual privacy and ensure that sentiment analysis is conducted responsibly, especially as insights from automated analyses increasingly inform business decisions.

III. METHODOLOGY

This study aims to analyze Amazon product reviews using sentiment analysis and topic modeling techniques to provide business insights. A structured approach was taken, including data preprocessing, topic modeling through Latent Dirichlet Allocation (LDA), and sentiment classification using machine learning models. This section outlines the methodology used, detailing each step in the process, including data handling, modeling, evaluation metrics, and final classification.

A. Dataset

The dataset consists of 3150 reviews from Amazon customers who purchased the Amazon Alexa product between May 2018 and July 2018 [7]. The dataset is an open dataset available at www.kaggle.com and there have been many research works conducted on it. The Amazon Alexa customer data has Alexa product reviews for 3 months and there are 5 columns of data provided; "rating" (comment score), "date" (comment date), "variation" (16 Alexa product variants), "verified_reviews" (the comment), and "feedback" (binary sentiment score based on the rating).

Fig. 2: Header of the dataset

	rating	date	variation	verified_reviews	feedback
0	5	31-Jul-18	Charcoal Fabric	Love my Echo!	1
1	5	31-Jul-18	Charcoal Fabric	Loved it!	1
2	4	31-Jul-18	Walnut Finish	Sometimes while playing a game, you can answer...	1
3	5	31-Jul-18	Charcoal Fabric	I have had a lot of fun with this thing. My 4 ...	1
4	5	31-Jul-18	Charcoal Fabric	Music	1

B.Data Exploration and Preprocessing

The methodology began with an exploration of the dataset, which included summarizing its structure, analyzing rating distributions, and generating descriptive statistics to understand review patterns and customer feedback. Data visualization through histograms was also performed to identify trends. Afterward, data preprocessing was conducted, which involved tokenization, stemming, lemmatization, stopword removal, and vectorization using the Bag of Words model to prepare the text for analysis [20], [21]. The next step involved creating the **corpus**, which refers to the body of tokenized text used for topic modeling. In this phase, a **document-term matrix** (DTM) was constructed, where each document (review) is represented by the frequency of words it contains. Additionally, a dictionary, called id2word, was created that assigns a unique identifier to each word in the corpus. The **corpus** and **id2word** dictionary serve as the two main inputs for the LDA model. The document-term matrix provides the frequency of words in each review, while the dictionary enables the model to map each word to its corresponding identifier.

C. Topic Modeling using LDA

The Latent Dirichlet Allocation (LDA) model was employed to discover hidden thematic structures within the Amazon reviews. LDA is a generative probabilistic model that assumes that each review is a mixture of several topics, and each topic is represented as a mixture of words. The objective was to identify the underlying customer interests and concerns from the product reviews. Each word in the document is assigned a probability distribution over a fixed number of topics, and each topic is represented as a distribution over words [22].Choosing the optimal number of topics (k) is a critical step in LDA. Different models were created with varying k values to test how well the topics represented the underlying structure of the reviews. The performance of these models was evaluated using two metrics: perplexity and topic coherence [23]. Latent Dirichlet Allocation (LDA) was selected as the topic modeling technique due to its effectiveness in identifying underlying thematic structures within large, unstructured datasets like customer reviews. LDA is particularly valuable for this study as it offers interpretability and helps uncover distinct topics, allowing businesses to better understand common customer concerns and preferences. Prior to applying the LDA model, several preprocessing steps were conducted to ensure data quality and relevance. This included removing noise (such as irrelevant words or special characters), handling duplicates to prevent data skewing, and filtering out reviews that did not provide meaningful feedback.

- **Perplexity** measures how well a probabilistic model predicts a sample. In topic modeling, it evaluates how surprised the model is when presented with unseen data. Lower perplexity values indicate that the model is better at capturing patterns in the data. However, perplexity alone is not always a reliable metric for evaluating topic models, as it tends to favour complex models.[23].
- **Topic Coherence** is another key evaluation metric that measures the semantic similarity between high-scoring words within a topic. Unlike perplexity, coherence is a human-centered measure that reflects how interpretable and meaningful the topics are to humans. A high coherence score indicates that the top words in a topic are closely related and make sense as a collective theme. For this study, the coherence score was prioritized as the primary metric, as it is a better indicator of meaningful and interpretable topics. The coherence score obtained for the optimal model was 0.476, which indicated a reasonably good level of interpretability [23].

D. Model Evaluation and Visualization

Once the LDA model was trained and evaluated, the next step involved visualizing the topics using the pyLDAvis package, a powerful tool for interpreting LDA results. The visualization provides an inter-topic distance map, where each circle represents a topic, and its size reflects the proportion of reviews attributed to that topic. Larger circles suggest more frequent topics. The distance between circles represents how distinct the topics are from one another [24].

In addition to the inter-topic distances, the pyLDAvis tool allows for visualizing the most relevant words for each topic. This helps in understanding the thematic structure of the reviews, revealing customer sentiments, product issues, or other underlying concerns [25].

E. Sentiment Classification using Machine Learning

After identifying the topics, various machine learning models, including Logistic Regression, KNN, SVM, Bagged Decision Trees, Random Forest, and ANN, were trained to classify the topics into positive or negative sentiments based on the feedback column [26]. Each model was evaluated using accuracy metrics to determine its predictive performance. Logistic regression emerged as the best-performing model, providing the highest accuracy in predicting whether a given review was positive or negative.

F. K-Fold Cross Validation

Cross-validation was employed to evaluate the performance of each machine learning model. Specifically, **k-fold cross-validation** (k=5 and k=10) was used to assess model generalizability. In this method, the dataset is randomly shuffled and split into k partitions. For each partition, the model is trained on k-1 partitions and tested on the remaining partition. The evaluation score from each fold is averaged to assess model performance [27].

G. Prediction of New Reviews

Finally, the trained logistic regression model was applied to predict the sentiment of new, unseen reviews. The process involved tokenizing the new review, transforming it into a numerical feature vector, and passing it through the

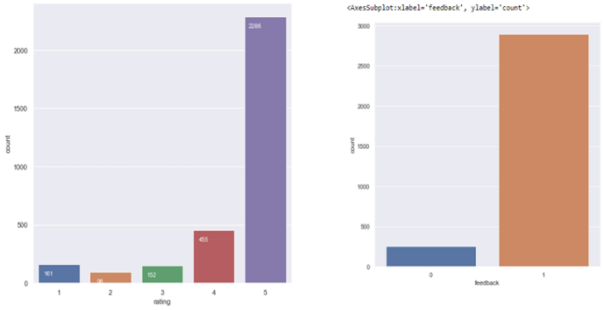
logistic regression model to predict its sentiment. The model provided a probability distribution over positive and negative labels, and the label with the highest probability was selected as the predicted sentiment.

IV. RESULTS

A. Exploratory Data Analysis on Dataset

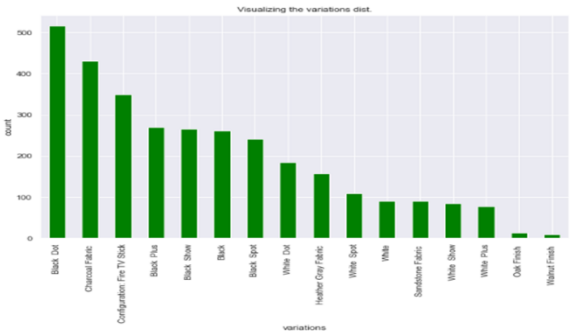
The dataset is initially analyzed using Python scripts. The data.info() function reveals column data types. Reviews are categorized by rating (1 to 5) and visualized to assess sentiment distribution. Additionally, feedback and the range of 16 different Alexa device types are examined to ensure comprehensive representation of product lines.

Fig. 3: Rating and feedback distributions.



The dataset distribution is according to the variety of Alexa devices. There are 16 different varieties in the dataset and the following distribution of those varieties.

Fig. 4: Verity of devices with the count of reviews Distribution.



A word cloud is generated to highlight the most frequently used positive and negative terms in the reviews. This visualization offers insights into common themes and sentiments expressed by users, which will be valuable in subsequent sentiment analysis.

Fig. 5: Word Cloud Positive and Negative

Task 01: Clustering Review and Identify Topics

B. Measuring the Model

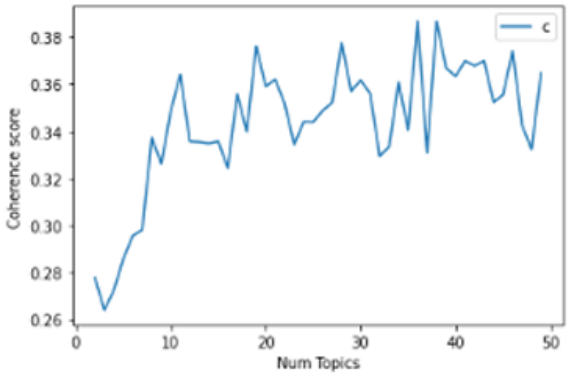
To assess the LDA model, both perplexity and coherence scores are calculated. For instance, when the topic count is set to 20, the perplexity and coherence values are obtained as follows:Perplexity: -10.3730,Coherence Score: 0.3185

These metrics serve as benchmarks to evaluate the effectiveness and relevance of the topics identified by the model.

C. Finding the Best Model

The optimal number of topics is determined using the coherence values for different topic counts (k). The coherence value is plotted against the number of topics, which aids in selecting the most suitable model for further analysis.

Fig. 6: Coherence value against number of topics.



A table summarizing the coherence values for topic counts ranging from 2 to 49 is also provided. The optimal model is identified when the number of topics equals 40, with a coherence score of 0.4041.

TABLE I: Coherence Value for Topics 2 - 49.

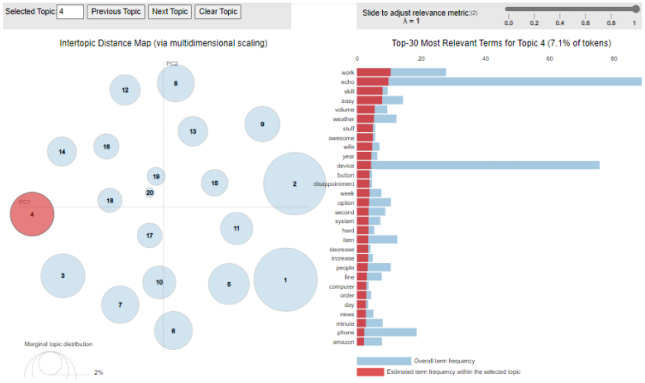
Num Topics = 2 has Coherence Value of 0.2288
Num Topics = 3 has Coherence Value of 0.2843
Num Topics = 5 has Coherence Value of 0.3151
Num Topics = 6 has Coherence Value of 0.3377
Num Topics = 7 has Coherence Value of 0.2885
Num Topics = 8 has Coherence Value of 0.335
Num Topics = 9 has Coherence Value of 0.3219
….
Num Topics = 45 has Coherence Value of 0.3699
Num Topics = 46 has Coherence Value of 0.3487
Num Topics = 47 has Coherence Value of 0.3812
Num Topics = 48 has Coherence Value of 0.3708
Num Topics = 49 has Coherence Value of 0.359
38 : Optimal Topic number = 40 Coherence Scores = 0.4041

D. Visualization for 20 Topics

A visualization of the LDA model with 20 topics is provided to offer a detailed view of how different topics are represented within the dataset. Each topic is displayed with its most relevant words, highlighting the thematic structure of the reviews.

Fig. 7: Visualization for 20 topics.

Topic 04

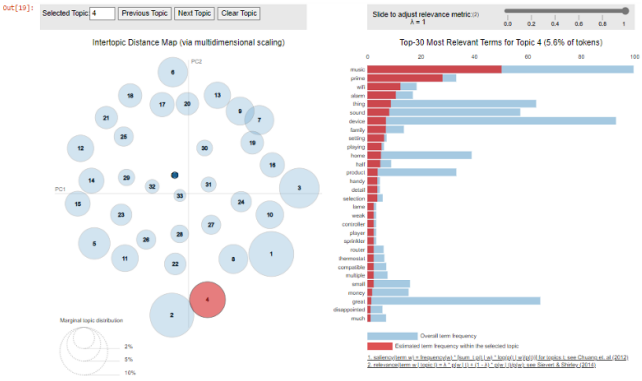


E. Visualization for 40 Topics – Best Fit LDA Model

A similar visualization is generated for the 40-topic model, which was found to be the best fit based on the coherence score. This representation allows for an in-depth understanding of the optimal topic structure and content clustering.

Fig. 8: Visualization for 40 topics.

Topic 04



Task 02: Comparison of Machine Learning Models Used to Identify the Type of Review

Multiple machine learning models are applied to classify the review types. The accuracies of each model, obtained using both normal test-train splits and k-fold cross-validation (k = 5 and k = 10), are compared to identify the best-performing model.

TABLE 2: ML Best Model Accuracies.

Created Model Name	Normal test and train split of 33% and 67% respectively	K fold cross validation k=5	K fold cross validation k=10
Logistic Regression	0.949	0.946	0.948
K-Nearest Neighbors (KNN)	0.886	0.933	0.937
Support Vector Machine (SVM)	0.930	0.923	0.925
Bagged Decision Trees (Bagging)	0.934	0.929	0.932
Random Forest	0.943	0.934	0.937
Neural Network	0.924	0.918	0.918

F. Topic Tagging

All topics predicted by the Logistic Regression model are tagged based on the identified keywords. These topics provide insights into the nature of the reviews, with positive and negative reviews labeled accordingly.

TABLE 3: Topic Tagging Results.

Topic	Tag
Topic: setup alarm many easy screen alexa several install simple home	A Positive Review
Topic: alexa part bedside ability instruction search clock music computer variety	A Positive Review
Topic: account device bluetooth echo manual personal membership respond star system	A Negative Review
Topic: equipment connectivity kid well good interact fast song dictionary player access need	A Positive Review
Topic: item purchase next work blue ready connect button echo light	A Positive Review
Topic: device echo home wifi problem original night well audio thing	A Positive Review
Topic: move card face dumb spot stupid super wall star clock	A Negative Review
Topic: house clock camera basic good show time display thing home	A Positive Review
Topic: volume enable speaker bass look less overdriven try34 time screen	A Positive Review
Topic: future bass exact surprised time fact small voice money well	A Positive Review
Topic: music love alarm light feature thing youtube great weather good	A Positive Review
Topic: thermostat music product tablet phone disappointed application	A Positive Review
Topic: phone number service device access able kind amazon sprint minimum	A Positive Review
Topic: equipment connectivity kid well good interact fast song dictionary player access need	A Positive Review
Topic: wifi speech router recognition office area thing wife intercom reception	A Positive Review
Topic: music sound quality prime speaker home need family device product	A Positive Review
Topic: gift birthday order package large step porch the open damage says but	A Positive Review
Topic: equipment connectivity kid well good interact fast song dictionary	A Positive Review
Topic: product nice star device loud work reason sure complaint alone	A Positive Review
Topic: device answer word echo little people screen time replacement light	A Positive Review
Topic: free screen month useful life bulb video device alexa good	A Positive Review
Topic: able price stupid music one thermostat rock dropping question else	A Positive Review
Topic: echo good sound day voice function weather convenient speaker	A Positive Review
Topic: great speaker happy weird reason time music noise interact major	A Positive Review
Topic : first fire amazon stick device horrible warranty againthis year major	A Positive Review
Topic : room program living request thing sling time respond speaker first	A Positive Review
Topic : trouble fault alexa apple product amazon speaker time music none	A Negative Review

V. DISCUSSION

The dataset consists of 3,150 reviews of various Amazon Alexa products, presenting a predominantly positive sentiment, with over 87% of the reviews rated favorably. This high proportion of positive reviews reflects a bias in the dataset, which posed challenges for balanced sentiment classification. The distribution of ratings, as visualized in the previous chapter, reveals that the majority of reviews were rated 5 or 4 stars, with very few negative ratings (i.e., ratings below 3). The imbalance in sentiment makes it more difficult to extract substantial insights from negative reviews, which, while fewer in number, are crucial for identifying potential areas of improvement for the product [9].

In terms of textual content, word clouds generated for both positive and negative reviews highlight different customer concerns. Words like "great," "love," and "music" are prominent in positive reviews, while words such as "device," "still," and "time" dominate the negative ones. These linguistic patterns suggest that while positive reviews often focus on the user experience and emotional connection with the product, negative reviews point to specific issues such as functionality and performance. [26].

A. Topic Identification Using LDA

One of the key objectives of this research was to provide insights into customer reviews by categorizing them into distinct topics. The LDA model was employed to group similar reviews into coherent topics, facilitating easier interpretation of customer feedback. Initially, 20 topics were generated, but through the evaluation of coherence and perplexity scores, it was determined that a 40-topic model provided the best fit. The topic coherence measure indicated the optimal number of topics for capturing the diversity of customer reviews while maintaining interpretability [25].

The 40-topic LDA model offered a robust framework for identifying trends and patterns within the dataset. For example, it helped categorize customer complaints about issues like "Bluetooth connectivity" and "speaker quality," while also identifying highly praised features such as "ease of setup" and "voice recognition." Each of these topics was tagged as either positive or negative, providing a structured summary of customer sentiments. This process demonstrated how topic modeling could distill unstructured data into actionable insights.

G. Performance of Machine Learning Models

Following the identification of topics, machine learning models were employed to classify these topics as positive or negative. The models used for this task included Logistic Regression, K-Nearest Neighbors (KNN), Support Vector Machine (SVM), Decision Trees, Random Forest, and a neural network. Logistic Regression outperformed the other models in terms of accuracy, making it the most suitable choice for predicting feedback polarity in this context. While the dataset imbalance posed challenges for some models,

cross-validation helped mitigate overfitting and provided a clearer understanding of model performance.

H. Business Insights from Topic Tagging

The main goal of this research was to extract business insights from the customer reviews by tagging the topics generated by the LDA model as positive or negative. With 40 distinct topics identified, the analysis revealed 37 positive topics and 3 negative topics. While the imbalance between positive and negative feedback limited the depth of the negative insights, the topics identified were still useful for understanding customer needs and potential product improvements. For instance, negative topics like "Bluetooth connection issues" and "speaker faults" provided specific areas where Amazon could focus on product enhancements. On the positive side, topics related to "ease of setup" and "functionality for kids" highlighted product features that customers appreciate. By analyzing these topics, the research offers valuable insights that can guide product development and customer service strategies.

I. Limitations

Several limitations were encountered during this research. The most significant of these was the size and imbalance of the dataset, which affected the generalizability of the results. With only 3,150 reviews and a strong bias toward positive comments, the models trained on this data may not perform as well on more balanced datasets. Another limitation was the inability to capture more nuanced forms of expression, such as sarcasm and irony, which can significantly affect the accuracy of sentiment classification. Additionally, while topic modeling provided valuable insights, not all topics were easily interpretable due to the ambiguity of certain terms.

Lastly, automatic topic labeling was not fully explored in this research, which limited the scalability of the approach. Future research could address these limitations by exploring larger, more balanced datasets and implementing more advanced techniques for automatic topic labeling.

VI. CONCLUSION

This research successfully conducted sentiment analysis on Amazon Alexa product reviews, focusing on extracting actionable business insights. The study began with an in-depth exploration of the dataset, utilizing visual representations to gain a comprehensive understanding of customer feedback. Data preprocessing techniques were effectively applied to prepare the reviews for analysis. The development and optimization of a Latent Dirichlet Allocation (LDA) model led to the identification of 40 coherent topics, which were subsequently labeled as either positive or negative using various machine learning models, including Logistic Regression, K-Nearest Neighbors (KNN), Support Vector Machine (SVM), Decision Trees, Random Forest, and a neural network. Notably, Logistic Regression emerged as the best-performing model for sentiment classification, demonstrating its efficacy in this context.The findings of this research provide valuable insights into customer sentiment, highlighting both areas of satisfaction and potential product improvements. The identification of 37 positive topics and 3 negative topics allows Amazon to pinpoint specific features that resonate with customers, such as "ease of setup" and "functionality for kids," while also addressing issues like "Bluetooth connection problems" and "speaker faults." This dual focus not only enhances customer satisfaction but also informs product development and marketing strategies.

From a practical standpoint, these insights can guide Amazon in refining their product offerings and enhancing customer support services. By leveraging the identified positive attributes, the company can further promote these features in marketing campaigns, while addressing negative feedback can lead to targeted improvements that increase user satisfaction and loyalty. Moreover, the study highlights the importance of continuous monitoring of customer feedback through sentiment analysis, enabling businesses to remain agile and responsive to changing customer needs. While the manual labeling of topics was feasible due to the limited topic set, the research notes that future work could benefit from automatic labeling techniques, especially as the volume of data increases. Addressing challenges such as sarcasm and irony in sentiment analysis and improving model performance on imbalanced datasets are critical areas for further research. By enhancing these aspects, future studies can provide even more nuanced insights into consumer sentiment and preferences, ultimately contributing to more effective business strategies.

REFERENCES

[1] Pattern, "Why Reviews Are Important on Amazon," Pattern.https://pattern.com/blog/why-are-reviews-on-amazon-important/ (accessed Jun. 20, 2022).

[2] Publons, "Publons.com." https://publons.com/ (accessed Jun. 20, 2022).

[3] Revain, "Why Are Customer Reviews So Important?," Medium.https://medium.com/revain/why-are-customer-reviews-so-important-185b915d4e5d (accessed Jun. 20, 2022).

[3] Revain, "Why Are Customer Reviews So Important?," Medium.https://medium.com/revain/why-are-customer-reviews-so-important-185b915d4e5d (accessed Jun. 20, 2022).

[4] Simplify Everything, "8 statistics on why you should care about local SEO," https://simplify-everything.com/en/blog/2019/10/17/8-statistics-on-why-you-should-care-about-local-seo-infographic/ (accessed Jun. 20, 2022).

[5] S. Yi and X. Liu, "Machine learning based customer sentiment analysis for recommending shoppers, shops based on customers' review," Complex Intell. Syst., vol. 6, no. 3, pp. 621–634, Oct. 2020, doi: 10.1007/s40747-020-00155-2.

[6] AMZ Insight, "Importance of Amazon Product Review and Rating for Sellers," Dec. 08, 2016. https://amzinsight.com/amazon-product-review-importance/ (accessed Jun. 20, 2022).

[7] Kaggle, "Sentiment Analysis of Alexa," https://kaggle.com/khushi08/sentiment-analysis-of-alexa (accessed Jun. 20, 2022).

[8] H. Zhang, Sentiment Analysis on Amazon Reviews, 2019, doi: 10.13140/RG.2.2.31090.53447.

[9] E. Gokce, "Sentiment Analysis on Amazon Reviews," Towards Data Science. https://towardsdatascience.com/sentiment-analysis-on-amazon-reviews-45cd169447ac (accessed Jun. 20, 2022).

[10] X. Fang and J. Zhan, "Sentiment analysis using product review data," J. Big Data, vol. 2, no. 1, p. 5, Jun. 2015, doi: 10.1186/s40537-015-0015-2.

[11] S.-M. Kim and E. Hovy, "Determining the Sentiment of Opinions," in COLING 2004: Proceedings of the 20th International Conference on Computational Linguistics, Geneva, Switzerland, Aug. 2004, pp. 1367–1373. Accessed: Jun. 20, 2022. [Online]. Available: https://aclanthology.org/C04-1200.
[12] B. Pang and L. Lee, "Opinion Mining and Sentiment Analysis," Found. Trends Inf. Retr., vol. 2, no. 1–2, pp. 1–135, Jul. 2008, doi: 10.1561/1500000011.
[13] P. D. Turney, "Thumbs Up or Thumbs Down? Semantic Orientation Applied to Unsupervised Classification of Reviews," arXiv, Dec. 11, 2002. Accessed: Jun. 22, 2022. [Online]. Available: http://arxiv.org/abs/cs/0212032.
[14] Keyhole, "How Does Sentiment Analysis Work?," Keyhole, Aug. 29, 2020. https://keyhole.co/blog/how-does-sentiment-analysis-work/ (accessed Jun. 22, 2022).
[15] G. Jeh and J. Widom, "Mining the Space of Graph Properties," Mar. 2003, doi: 10.1145/1014052.1014075.
[16] B. Liu, Sentiment Analysis and Subjectivity, p. 38.
[17] R. Brown, "Sentiment Analysis: How it Works, Types & Everything You Need to Know," Medium, Mar. 04, 2021. https://cogitotech.medium.com/sentiment-analysis-how-it-works-types-everything-you-need-to-know-822a1f2ddeaf (accessed Jun. 22, 2022).
[18] D. Mohey El-Din, "Analyzing Scientific Papers Based on Sentiment Analysis (First Draft)," 2016, doi: 10.13140/RG.2.1.2222.6328.
[19] W. Karwowski, Advances in the Human Side of Service Engineering, Jan. 2012. Accessed: Jun. 24, 2022. [Online].
[20] "GreTap94.pdf." Accessed: Jun. 27, 2022. [Online]. Available: in.net/courses/07/nlp/Gre:Tap:94.pdf.
[21] D. D. Palmer, "Chapter 2: Tokenisation and Sentence Segmentation," p. 23.
[22] "Perplexity To Evaluate Topic Models." http://qpleple.com/perplexity-to-evaluate-topic-models/ (accessed Jun. 29, 2022).
[23] R. Kulshrestha, "A Beginner's Guide to Latent Dirichlet Allocation (LDA)," Towards Data Science. https://towardsdatascience.com/latent-dirichlet-allocation-lda-9d1cd064ffa2 (accessed Jun. 27, 2022).
[24] R. Kulshrestha, "Latent Dirichlet Allocation (LDA)," Medium, Sep. 28, 2020. https://towardsdatascience.com/latent-dirichlet-allocation-lda-9d1cd064ffa2 (accessed Jun. 27, 2022).
[25] Analytics Vidhya, "Topic Modeling and Latent Dirichlet Allocation (LDA) using Gensim," Analytics Vidhya, Jun. 28, 2021. https://www.analyticsvidhya.com/blog/2021/06/part-2-topic-modeling-and-latent-dirichlet-allocation-lda-using-gensim-and-sklearn/ (accessed Jun. 27, 2022).
[26] K. Ganesan, "Build Your First Text Classifier in Python with Logistic Regression," Kavita Ganesan, PhD, Jul. 25, 2019. https://kavita-ganesan.com/news-classifier-with-logistic-regression-in-python/ (accessed Jun. 25, 2022).
[27] J. Brownlee, "A Gentle Introduction to k-fold Cross-Validation," Machine Learning Mastery, May 22, 2018. https://machinelearningmastery.com/k-fold-cross-validation/ (accessed Jul. 02, 2022).

Intelligent Road Safety Navigation in Sri Lanka: A Review of Machine Learning Techniques and Proposal of a Model for Predicting Accident Hotspots and Severity

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***Abstract* - Both public safety and the stability of the economy are seriously threatened by traffic accidents. Like many other regions, Sri Lanka is faced with the challenge of road accidents, which hinder the path to safer roads. One of the reasons that accidents occur is that people are unaware of common accident locations. The government has already enforced other tactics, like traffic signals and fines, to reduce these incidents, but they have been ineffective. In order to decrease road accidents, people must change their driving patterns. While looking for a solution to that problem, existing studies around the world have proposed predictive machine learning models for accident-prone locations known as hotspots and severity levels. But there were not any existing studies that proposed a solution that was suitable for Sri Lanka. This research seeks to address these challenges by conducting an in-depth review of existing machine learning techniques and proposing the most suitable model approaches for prediction of accident hotspots and severity in Sri Lanka based on the availability of the accident data. One of the main objectives is to identify the correct machine learning techniques. According to studies, 81% used the 'Random Forest' algorithm, which is a supervised machine learning algorithm for the prediction. And Random Forest performed better in approximately 69% of the studies. And this research is not just proposing suitable model approaches for predictions. It provides the foundation to revolutionize road safety through the development of an intelligent road safety mobile navigation application.**

Keywords - Predictive Models, Machine Learning (ML), Hotspots Identification, Severity Analysis

I. INTRODUCTION

In recent decades, the number of vehicles on the roads has notably risen, which results in congested highways. This huge traffic load has pushed up the road accident graph, increasing injuries and deaths globally. Children who suffer injuries or pass away accidentally have a significant effect on society and families.

The World Health Organization (WHO) estimates that up to 3,700 people per day are killed in automobile accidents, accounting for around 1.19 million annual fatalities. [1] There are an additional 20 to 50 million non-fatal injury cases, many of which result in disability. According to statistics from the Ministry of Transport and Highways, in 2022, Sri Lanka recorded 21,953 road accidents.[2] Not only have accidents caused more deaths or injuries, but they have also increased the financial damage to public property. One of the reasons that accidents occur is that people are unaware of common accident locations. While many accident causes appear to be similar and may be managed together, the actual causes of traffic accidents vary from state to state based on their level of development. As a result, it is critical to reducing the number of traffic accidents that occur every day. The government has already enforced other tactics, like traffic signals and fines, to reduce these incidents, but they have been ineffective. But in order to decrease accidents, people must change their driving patterns.

This research seeks to address these challenges by proposing an in-depth review of existing machine learning techniques for road accident hotspots and severity prediction in Sri Lanka. The primary objective is to identify the correct machine learning techniques for predicting accident hotspots and severity and provide the most suitable model approaches for the predictions.

Going beyond theoretical modeling, this study uses the insights from the evaluation of these predictive models as the foundation for an intelligent road safety mobile navigation application. This application is designed to enable immediate responses and interventions, enhancing road safety practices in Sri Lanka.

The rest of this paper is organized as follows: Section II introduces some previous work and existing machine learning techniques for road accident hot spot prediction. Section III describes the methodology. Section IV introduces the results of this study through discussion. Sections V and VI give the conclusion and future work.

II. LITERATURE REVIEW

A. Existing studies on implementing predictive models for accident hotspots and severity.

Existing studies on implementing predictive models for accident hotspots and severity that are specifically tailored for their own accident data are discussed below,

demonstrating that machine learning techniques performed better as predictors than statistical techniques.A study by Jayesh Patil et al. aims to develop an application connected to maps that gives a user a clear idea of accident-prone areas, passes an alert about road conditions, and suggests certain ways to be safe. The goal of this study is to lower the mortality rate by developing a prediction model using the unsupervised learning technique known as k-means clustering, which analyzes traffic accidents by taking into account various factors such as potholes in the road, sharp turns, and weather conditions, and then offers appropriate and preventative measures to avoid accidents by representing them on a map and building an understandable model for everyone. The accuracy of the anticipated model was 81% [3] .

In a paper by Aklilu Elias Kurika et al., the authors discussed how predictions of vehicular accidents were determined using a machine learning system.The data for the projection was taken from Wolaita Zone's 12 districts and three municipal administrations. The experimental findings, model assessment, and performance measurement revealed that the J48 and Rep tree classifiers' F-measure was equivalent (decision tree classifiers (J48, Random Forest, and Rep Tree)), while the Random Forest tree performed poorly. Based on performance, the J48 tree was determined to be the best model [4].

A research study by Teres Augustine et al. proposes an accident prediction system that can help analyze potential safety issues and predict whether an accident will occur or not. A comparative study of various machine learning algorithms was conducted to check which model could help predict accidents more accurately. The dataset used for this paper is the government record of accidents that occurred in a district in India. The machine learning models utilized in this study to predict accidents are Logistic Regression, Random Forest, Decision Tree, K-Nearest Neighbor, XGBoost, and Support Vector Machine. The Random Forest algorithm gave the highest accuracy of 80.78% when the accuracies of the machine learning models were compared [5].

Mahendra G et al.'s article forecasts traffic accidents by taking into account four factors: location, weather, road type, and collision type. A machine learning model that combines a decision tree and random forest regressor is being created and is currently in use to forecast collisions based on collision statistics from various Indian states. The Random Forest Regressor (RFR) model outperforms the Decision Tree Regressor (DTR) model, according to the results of the relative analysis.[6]

Daniel Santos et al.'s article seeks to create models that can identify a subset of important variables that can be utilized to categorize an accident's severity in order to enable a study of the accident data. Furthermore, based on historical data, this study suggests a predictive model for upcoming traffic incidents. Both supervised and unsupervised machine learning approaches such as hierarchical clustering and DBSCAN are employed, along with supervised machine learning strategies including decision trees, random forests, logistic regression, and naive Bayes. The predictive model's output indicates that the RF model might be a helpful tool for predicting accident hotspots.[7]

Study by Brunna de Sousa Pereira Amorim et al., Several machine learning methods were used in order to determine which feature combination would yield the best classifier for Brazilian federal road hotspots linked to either a severe or non-severe accident probability. SVM, random forest, and a multi-layer perceptron neural network were used for testing. A ten-year report on traffic accidents from the Brazilian Federal Highway Police is included in the dataset. The outcomes of the analysis are the following features set including as aspects of road types, the route, the direction, weather conditions, types of the accidents, spatial extent of the accident, day of the week, and the hour of the day when the accident occurred. Hence, the proposed neural network model gave the desired outcome with the accuracy: Accuracy: 83%, precision: 84%, recall: 83%& F1 Score: 82%. The results were encouraging. The results were encouraging. [8]

Study by R. Vanitha et al., They employed machine learning approaches, such as Decision Tree, Random Forest, and Logistic Regression, to build an accident prediction model. These classification schemes will be useful for both accident prediction and safety measure creation. Road surface conditions, weather, vehicle condition, and lighting conditions are some of the factors that are used to forecast traffic accidents. Additionally, the RF model offered 86.86% greater accuracy.[9].

Study by Abdelilah Mbarek et al., created a model with the purpose of identifying, categorizing, and analyzing black patches on Moroccan highways. Ordinal regression is used to examine the infrastructure factors once the extreme learning machine (ELM) technique has been used to identify these areas. The weighted severity index (WSI), which in turn produces the severity scores to be allocated to specific road segments, is generated using the XGBoost model. After that, the latter are categorized using a four-class system (high, medium, low, and safe). The results of the simulation demonstrate that the suggested framework surpassed the reliable competing models, particularly in terms of accuracy, which was 98.6%, and correctly and efficiently recognized the black areas.[10]

Study by Rabia Emhamed et al., investigates models in order to identify a subset of significant variables and construct a model for categorizing the severity of injuries. These models are created using a variety of machine learning methods. Examples of the supervised machine

learning algorithms like AdaBoost, Logistic Regression (LR), Naive Bayes (NB), and Random Forests (RF) constructed from the data of traffic accidents. When the data sets are unbalanced, a particular method known as the SMOTE method is followed. Based on the results of the study, this paper has revealed that RF model has the potential of being used to forecast on the severity of the accidents. As far as the accuracy is concerned, the RF is higher than the accuracy of LR (74. 5%), NB (73. 1%), AdaBoost (74. 5%). Accuracy of the RF algorithm is 75. 5%..[11]

Study by Jian Zhang et al., In this study, the predictive performance of various machine learning and statistical approaches with various modeling logics for crash severity analysis is compared in terms of variable importance estimation and prediction accuracy. Data on traffic flow, road shape, and crash severity were collected in Florida's highway diverge regions. The ordered probit (OP) model and the multinomial logit (MNL) model, two of the most widely used statistical models, were computed in addition to four widely used machine learning models: Support Vector Machines (SVM), Random Forest (RF), Decision Trees (DT), and K-Nearest Neighbors (KNN). The findings demonstrated that machine learning techniques performed better as predictors than statistical techniques. For both overall and severe crashes, the RF technique produced the best forecast, while the OP method produced the lowest estimate.[12]

Study by Md. Kamrul Islam et al., In order to forecast the severity of road traffic crashes (R.T.C.s.), this study contrasts a logistic regression model with tree-based ensemble methods (random forest and gradient boosting). Random forest (R.F.) is used to identify significant traits that are significantly correlated with the severity of the R.T.C.s. The investigation's findings showed that the type of collision and its cause are the two main variables affecting how seriously people are injured in traffic accidents. The random forest (R.F.) strategy fared better than other models when using k-fold (k = 10) in terms of injury severity, individual class accuracies, and collective prediction accuracy, based on several performance metrics. [13]

Research review by Kenny Santos et al., provides a current assessment of the research on the techniques used in injury severity modeling from traffic crashes. 56 research that span the years 2001 to 2021 and take into account more than 20 distinct statistical or machine learning methods are included. Findings: Of all the algorithms tested, Random Forest produced the best outcomes in 29% of the studies and 70% of the applications. In 53% and 31% of cases, as well as in 16% and 14% of all trials, Support Vector Machine and Decision Tree had the best performance, respectively. Although they were employed 67% and 40% of the time, respectively, Bayesian Networks and K-Nearest Neighbors performed best in only 4% and 7% of the studies that were examined. [14]

Study by Buket Geyik et al., uses prior knowledge as training data to classify data objects into groups, which is useful for us to work with. The models that we used are Multilayer Perceptron (MLP), decision tree classifier, random forest classifier, Naïve Bayes classifier. Three categories of accident severity were applied to the dataset: These include minor infection, serious infection and death. The goal of the study is to establish models to predict the accident severity levels of traffic accident injury records for potential accidents by using some data mining classification methods. The findings of the evaluated classification methods show that the MLP model has an accuracy of 86.67%, the decision tree algorithm has an accuracy of 80.74%, the random forest classifier has an accuracy of 85.19%, and the Naive Bayes strategy has an accuracy of 83.40%.[15]

Study by Imad EL MALLAHI et al., concentrate on predicting the severity of traffic accidents, as this is a critical step in managing accidents on the road. In order to categorize and forecast the severity of traffic accidents, the Random Forest, Support Vector Machine, and Artificial Neural Network methods are used in this suggested study and compared. They divide the severity prediction of traffic accidents into three classes using accident data: pedestrian, vehicle or pillion passenger, and driver or rider. At the precision recall level, they have 93.82% compared to 82.22% for SVM and 87.88% for ANN, and they have 93% accuracy for random forest. [16]

Study by Tariq Al-Moqri et al., Their main goal is to evaluate the role of the main contributors to the severity of injuries. Traditional statistical methods were contrasted with the chosen machine learning algorithms. Three types of injury severity were identified in the accident data: Severe, Serious, and Minor. A synthetic minority oversampling approach (SMOTE) was used to achieve balance. The five machine learning classifiers, Naïve Bayes (NB), J48 Decision Tree, Random Forest (RF), Support Vector Machine (SVM), and Multilayer Perceptron (MLP), were compared with the Multinomial Logit Model (MNL).With an accuracy rate of 94.84%, RF is the best classifier out of five.[17]

J. Best performing machine learning technique for accident hotpots and severity prediction analysis

Table 1 Existing Machine Learning techniques used for the predictions

Author	Machine Learning Techniques Used	Best Performing ML Technique	Prediction Focus

Jayesh Patil et al. [3]	K-means Clustering	K-means Clustering	Accident Hotspot
Daniel Santos et al. [7]	Hierarchical clustering, DBSCAN, Decision trees, Random Forest, Logistic regression, Naive Bayes	Random Forest	Accident Hotspot
Aklilu Elias Kurika et al.[4]	J48, Rep Tree classifiers	J48	Accident Hotspot
Mahendra G et al.[6]	Decision Tree, Random Forest Regressor	Random Forest Regressor	Accident Hotspot
R.Vanitha et al. [9]	Decision Tree, Random Forest, Logistic Regression	Random Forest	Accident Hotspot
Abdelilah Mbarek et al. [10]	Extreme Learning Machine (ELM), XGBoost	XGBoost	Accident Hotspot
Jian Zhang et al. [12]	KNearest Neighbor, Decision Tree, Random Forest, Support Vector Machine	Random Forest	Accident Hotspot
Tao Lu et al. [18]	Logistic regression, Random Forest	Random Forest	Accident Hotspot
Kenny Santos et al. [14]	Random Forest, Support Vector Machine, Decision Tree, Bayesian Networks, K-Nearest Neighbors	Random Forest	Accident Hotspot
Rabia Emhamed et al. [11]	AdaBoost, Logistic Regression, Naive Bayes, Random Forests	Random Forest	Accident Severity
Brunna de Sousa Pereira Amorim et al. [8]	SVM, Random Forest, Multi-layer perceptron neural network	Multi-layer perceptron NN	Accident Severity
Teres Augustine et al. [13]	Logistic Regression, Random Forest, Decision Tree, K-Nearest Neighbor, XGBoost, Support Vector Machine	Random Forest	Accident Severity
Md. Kamrul Islam et al. [10]	Logistic Regression, Random Forest, Gradient Boosting	Random Forest	Accident Severity
Buket Geyik et al. [15]	Multilayer Perceptron (MLP), Decision Tree, Random Forest, Naive Bayes	MLP	Accident Severity
Imad EL MALLAHI et al. [16]	Random Forest, Support Vector Machine, Artificial Neural Network	Random Forest	Accident Severity
Tariq Al-Moqri et al. [17]	Naïve Bayes, J48 Decision Tree, Random Forest, Support Vector Machine, Multilayer Perceptron	Random Forest	Accident Severity

III. METHODOLOGY

This section describes research design, study population, data collection methods, model development.

Quantitative and qualitative approaches will be used for this research, and the Mount Lavinia region of the Colombo district of the western province of Sri Lanka will be the study population.

A. Data collection

The data collection methods will be past police accident reports and interviews. The past police accident reports will be used to collect road accident data. The interviews will be used to collect ideas and thoughts from the officers of the police stations and relevant authorities.

Based on the analysis of the data that were collected from the existing studies, the accident data is categorized as given below in table 2 and will be hoped to collect in partnership with the mount Lavinia police station.

Table 2 Accident data

Road accident locations coordinates (latitude and longitude)
Date (Day of the week)
Time (Hour of the day)
Accident location severity levels (fatal, critical, minor, damages only)
Weather condition
Vehicle types involved
Number of people injured
Age of the Driver
Gender of the Driver
Reason for the accident
The total number of reported road traffic accident cases, deaths (fatal), critical, minor, and damages only, for the years 2020, 2021, 2022, and 2023

B. ML Model Development:

1) Proposed model solution for prediction of accident hotspots

According to the collected data and the critical review of the existing research papers, the following proposed model will be use for the prediction of accident hotspots.

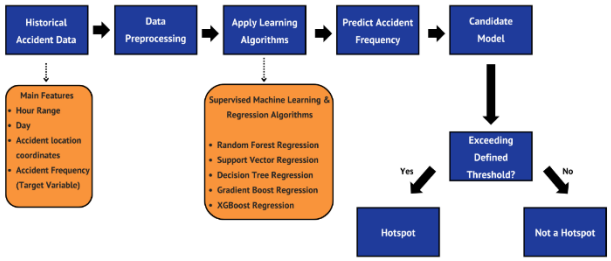

Fig. 1 Proposed model for prediction for hotspots.

.The goal of accident frequency prediction is to project the probability that accidents will occur in a given area in the future. An accident hotspot is a location, whether it be a connection or a node, that has unusual crash frequencies or rates. By comparing the accident frequency with the defined threshold value, accident hotspots can be predicted.

As shown in Fig. 1, for the model selection, supervised machine learning and regression algorithms will be used to train the models since the collected data consist of a labeled data set and has a continuous target variable called accident frequency (accident count).

Based on the collected historical accident data that is shown in Tables 6 and 7, hour-range, day, coordinates of the accident location, and accident count were the features that were used for this hotspot prediction.

Right after the selection of the features for the prediction, the data preprocessing will be conducted. Cleaning and preparing data for a machine learning model requires data preprocessing, which also increases the model's efficacy and accuracy.

After completion of data preprocessing, it will come to the next stage that focuses on applying machine learning algorithms. Based on the usage of machine learning techniques that were shown in Table 1, regression models such as random forest regression, gradient boost regression, support vector regression, decision tree regression, and XGBoost regression will be used to predict the accident frequency. And the model that provides better accuracy will be chosen for further fine-tuning to increase accuracy. Once the fine tuning is done with the chosen model, it'll be considered as the candidate model.

After successfully predicting the accident frequency, the threshold value for accident frequency will be obtained by calculating the mean of the accident count. And the coordinates (locations) exceeding this threshold value are considered hotspots, which will be the final prediction of the candidate model.

2) Proposed model solution for prediction of accident severity

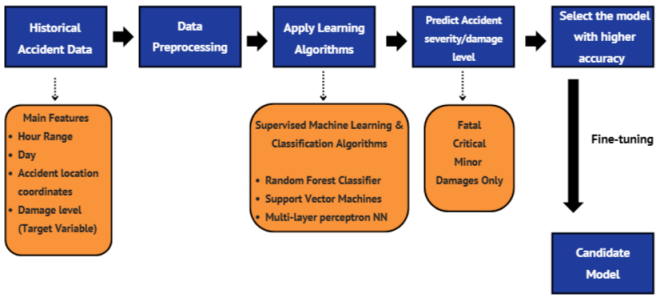

Fig. 2 Proposed model for prediction of severity.

As shown in Fig. 2, the proposed solution for accident severity prediction is: Since the severity level of the accident hotspot is classified into four levels, such as "fatal," "critical," "minor," and "damages only," which was the target variable for the model selection, supervised machine learning and classification algorithms will be used rather than regression algorithms.

Based on the collected historical accident data that is shown in Table 3, hour-range, day, coordinates of the accident location, and damage level were the features that were used for this severity prediction. This model also conducted the data preprocessing right after the selection of the features for the prediction.

After completion of data preprocessing, it will come to the next stage, which focuses on applying machine learning algorithms. Based on the usage of machine learning techniques that were shown in Tables 6 and 7, classification models such as random forest classifiers, XGBoost, multi-layer perceptron NN, and support vector machines will be used to predict the damage level and severity. And the model that provides better accuracy will be chosen for further fine-tuning to increase accuracy. Once the fine tuning is done with the chosen model, it'll be considered as the candidate model.

IV. Results & Discussion

A. Data collection and analysis

In this study, a comprehensive evaluation of the data collected from the Mount Lavinia region in Colombo, Sri Lanka was conducted.

The past police accident reports are used to collect road accident data, and accident data collected from the Mount Lavinia police station is given below in table 3.

Table 3 Collected Accident Data

Road accident locations coordinates (latitude and longitude)
Date (Day of the week)
Time (Hour of the day)
Accident location severity levels (fatal, critical, minor, damages only)
The total number of reported road traffic accident cases, deaths (fatal), critical, minor, and damages only, for the years 2020, 2021, 2022, and 2023

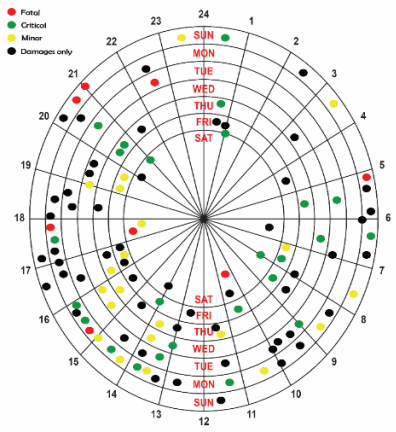

Fig. 3 Time Clock with damage severity.

Fig. 3 shows the days and times when traffic accidents occurred in the Mount Lavinia region in 2023 (with damage severity).

Fig. 4 Road accident hot spots.

Fig. 4 is a map showing traffic accident locations, also called "hot spots," in the Mount Lavinia region in 2023. These accident hotspots are divided into four levels of damage severity (fatal, critical, minor and damage). only). According to Figure 3, most traffic accidents occurred near intersections.

Table 4

Number of Road Accidents in Mount Lavinia Police Area				
Damage Level	2020	2021	2022	2023
Fatal	02	10	13	09
Critical	38	36	36	31
Minor	40	30	26	22
Damages only	64	42	48	51
Total	144	118	123	113
Deaths	02	10	13	09

According to the collected data from the police station, Table 4 shows the number of road accidents and deaths in the Mount Lavinia region based on the severity of the damage.

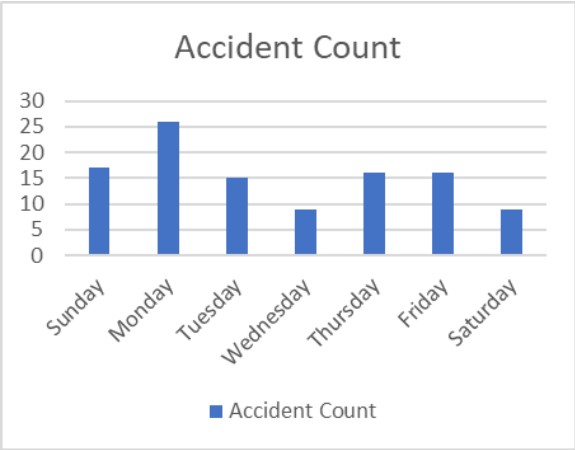

Fig. 5

According to Fig. 5, most traffic accidents occurred on Monday.

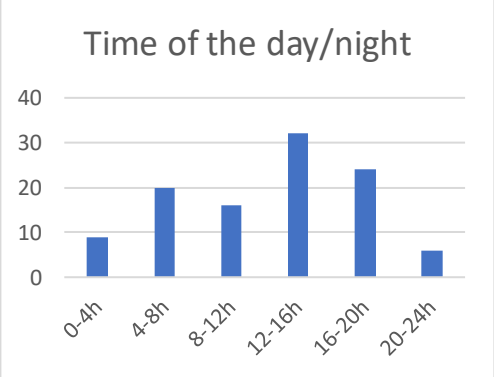

Fig. 6

According to Fig. 6, most traffic accidents occurred in between 12-to-16-hour range.

B. Input Features for the proposed models in Figure 1,2

Table 5 Selected features

Prediction Type	Features	Target Variable
Accident Hotspot	Hour Range	Accident Count
	Day	
	Latitude	
	Longitude	
Accident Severity	Hour Range	Damage Level
	Day	
	Latitude	
	Longitude	

C. *Selection of machine learning technique for the proposed models*

Table 6 Usage of machine learning techniques

Machine learning techniques	Usage Percentage (%)
Random Forest	81.25%
Decision Tree	50%
Support Vector Machine	37.5%
Logistic Regression	37.5%
Naïve Bayes	25%
K-Nearest Neighbor	18.75%
Multi-Layer perceptron neural network (MLP)	18.75%
XGBoost	12.5%
J48	12.5%
K-means Clustering	6.25%
Hierarchical Clustering	6.25%
DBSCAN	6.25%
Extreme Learning Machine (ELM)	6.25%
Bayesian Networks	6.25%
AdaBoost	6.25%
Artificial Neural Network	6.25%

Table 7 Usage of Best performing machine learning techniques

Machine learning techniques	Performance Percentage (%)
Random Forest	68.25%
Multi-Layer perceptron neural network (MLP)	12.5%
XGBoost	6.25%
J48	6.25%
K-means Clustering	6.25%

Random Forest is a supervised machine learning technique that was employed for prediction in 81.25% of the examined research publications, according to the analysis of tables 6 and 7. Labeled data is used to train supervised machine learning algorithms, which then learn to produce output according to the input features.

And among the supervised machine learning techniques, Random Forest performed better in terms of accuracy in approximately 69% of the studies.

Even though the Random Forest model did provide better accuracy for both accident hotspots and severity than the other techniques, since this study focused on implementing a predictive machine learning model that was specifically tailored for Sri Lankan accident data and there were no existing studies designed for Sri Lankan accident data, the Random Forest model will be compared with other machine learning techniques that were shown in existing

studies in Tables 6 and 7. And the model that provides better accuracy will be chosen as the final model.

V. CONCLUSION

In conclusion, this research journey has shed light on the critical issue of road safety in Sri Lanka and similar regions, emphasizing the need for innovative approaches to accident prediction. The substantial human and economic losses resulting from road accidents necessitate immediate and data-driven solutions.

By methodically exploring and reviewing existing machine learning techniques for accident prediction and severity analysis, we have uncovered valuable insights into the potential for enhancing road safety practices. Our focus on the Mount Lavinia region of Colombo, Sri Lanka, and the comprehensive data collection methods, including accident hotspot coordinates, severity levels, day and time, accident reasons, and accident cases for multiple years, as well as the proposed machine learning models for the predictions, have provided a foundation for this research.

Most notably, a review of numerous predictive models confirms that the random forest model, a supervised machine learning technique, consistently outperforms other methods in terms of accuracy for predicting accident hotspots and severity.

And this proposed machine learning models are aimed at enhancing road safety through an "Intelligent Road Safety Mobile Navigation Application" that is going to provide alerts on accident hotspots and severity to drivers in real time. In Sri Lanka, no such kind of application has been developed yet. And it helps drivers adjust their driving patterns, which encourages the use of technology for greater excellence, will have a sizeable effect on avenue safety practices, and will doubtless save lives. This study isn't pretty much instructional overall performance; it's a sensible technique for an actual global problem that impacts countless human beings each day.

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REFERENCES

[1] "Road traffic injuries." Accessed: Apr. 18, 2024. [Online]. Available: https://www.who.int/news-room/fact-sheets/detail/road-traffic-injuries

[2] "National Council for Road Safety." Accessed: Jul. 06, 2024. [Online]. Available: https://www.transport.gov.lk/web/index.php?option=com_content&view=article&id=29&Itemid=149&lang=en#road-accidents

[3] J. Patil, V. Patil, D. Walavalkar, and V. B. Lobo, "Road Accident Analysis and Hotspot Prediction using Clustering," in *2021 6th International Conference on Communication and Electronics Systems (ICCES)*, Jul. 2021, pp. 763–768. doi: 10.1109/ICCES51350.2021.9489074.

[4] I. Ganie, "Predicting Factors of Vehicular Accidents using Machine Learning Algorithm," vol. 9, Oct. 2020, doi: 10.30534/ijeter/2020/46892020.

[5] T. Augustine and S. Shukla, "Road Accident Prediction using Machine Learning Approaches," in *2022 2nd International Conference on Advance Computing and Innovative Technologies in Engineering (ICACITE)*, Apr. 2022, pp. 808–811. doi: 10.1109/ICACITE53722.2022.9823499.

[6] M. G and R. H. R, "Prediction of Road Accidents in the Different States of India using Machine Learning Algorithms," in *2023 IEEE International Conference on Integrated Circuits and Communication Systems (ICICACS)*, Feb. 2023, pp. 1–6. doi: 10.1109/ICICACS57338.2023.10099519.

[7] D. Santos, J. Saias, P. Quaresma, and V. B. Nogueira, "Machine Learning Approaches to Traffic Accident Analysis and Hotspot Prediction," *Computers*, vol. 10, no. 12, Art. no. 12, Dec. 2021, doi: 10.3390/computers10120157.

[8] B. de S. P. Amorim, A. A. Firmino, C. de S. Baptista, G. B. Júnior, A. C. de Paiva, and F. E. de A. Júnior, "A Machine Learning Approach for Classifying Road Accident Hotspots," *ISPRS Int. J. Geo-Inf.*, vol. 12, no. 6, Art. no. 6, Jun. 2023, doi: 10.3390/ijgi12060227.

[9] R. Vanitha and S. M, "Prediction of Road Accidents using Machine Learning Algorithms," May 18, 2023, *Rochester, NY*: 4460883. Accessed: Sep. 30, 2023. [Online]. Available: https://papers.ssrn.com/abstract=4460883

[10] A. Mbarek, M. Jiber, A. Yahyaouy, and A. Sabri, "Black spots identification on rural roads based on extreme learning machine," *Int. J. Electr. Comput. Eng. IJECE*, vol. 13, no. 3, Art. no. 3, Jun. 2023, doi: 10.11591/ijece.v13i3.pp3149-3160.

[11] R. E. AlMamlook, K. M. Kwayu, M. R. Alkasisbeh, and A. A. Frefer, "Comparison of Machine Learning Algorithms for Predicting Traffic Accident Severity," in *2019 IEEE Jordan International Joint Conference on Electrical Engineering and Information Technology (JEEIT)*, Apr. 2019, pp. 272–276. doi: 10.1109/JEEIT.2019.8717393.

[12] J. Zhang, Z. Li, Z. Pu, and C. Xu, "Comparing Prediction Performance for Crash Injury Severity Among Various Machine Learning and Statistical Methods," *IEEE Access*, vol. PP, pp. 1–1, Oct. 2018, doi: 10.1109/ACCESS.2018.2874979.

[13] M. K. Islam, I. Reza, U. Gazder, R. Akter, M. Arifuzzaman, and M. M. Rahman, "Predicting Road Crash Severity Using Classifier Models and Crash Hotspots," *Appl. Sci.*, vol. 12, no. 22, Art. no. 22, Jan. 2022, doi: 10.3390/app122211354.

[14] K. Santos, J. P. Dias, and C. Amado, "A literature review of machine learning algorithms for crash injury severity prediction," *J. Safety Res.*, vol. 80, pp. 254–269, Feb. 2022, doi: 10.1016/j.jsr.2021.12.007.

[15] B. Geyik and M. Kara, "Severity Prediction with Machine Learning Methods," in *2020 International Congress on Human-Computer Interaction, Optimization and Robotic Applications (HORA)*, Jun. 2020, pp. 1–7. doi: 10.1109/HORA49412.2020.9152601.

[16] I. E. Mallahi, A. Dlia, J. Riffi, M. A. Mahraz, and H. Tairi, "Prediction of Traffic Accidents using Random Forest Model," in *2022 International Conference on Intelligent Systems and Computer Vision (ISCV)*, May 2022, pp. 1–7. doi: 10.1109/ISCV54655.2022.9806099.

[17] T. Q. S. Abdullah, H. Xiao, J. P. Namahoro, E. Alfalahi, and I. Al-Wesabi, "Exploiting Machine Learning Algorithms for Predicting Crash Injury Severity in Yemen: Hospital Case Study," *Appl. Comput. Math.*, vol. 9, pp. 155–164, Sep. 2020, doi: 10.11648/j.acm.20200905.12.

[18] T. Lu, Z. Dunyao, Y. Lixin, and Z. Pan, "The traffic accident hotspot prediction: Based on the logistic regression method," in *2015 International Conference on Transportation Information and Safety (ICTIS)*, Jun. 2015, pp. 107–110. doi: 10.1109/ICTIS.2015.7232194.

Electrical, Electronic, Mechanical and Systems Engineering

Indoor Positioning using Visible Light Communications

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***Abstract*— Visible light communication (VLC) has become extremely well-known since it can use transmitter LEDs for both communication and illumination. In situations where wireless communication is not preferred, such as hospitals and other chemical industries, VLC can be used. Although GPS is widely used, VLC's capacity to resist loss and jamming in an interior environment enables it to offer data with higher accuracy. Visible light communication (VLC) is a wireless technology that has the potential to offer high-speed, secure, and energy-efficient communication. The goal of the research was to create an indoor positioning system that transmits data using VLC between a receiver device and several mounted light sources in the surroundings. Based on the received light signals, the system was built to precisely determine the receiver's location and show that location on a graphical user interface. The study effectively illustrated the viability of utilizing VLC for indoor location and offered insightful information regarding the difficulties and potential uses of VLC technology in the future.**

Keywords*— *Visible light communication (VLC), Light Emitting diodes (LEDs), Indoor Positioning systems (IPS), Global positioning systems (GPS), On-Off Keying (OOK), Received signal strength (RSS)

I. INTRODUCTION

The way people connect and communicate with one another now is entirely different as a result of wireless communication. Guglielmo Marconi created the first wireless communication system in the late 19th century, and since then the field of wireless communication has expanded enormously. However, the increasing use of wireless communication systems has led to a scarcity of available bandwidth in the RF (radio frequency) spectrum. As a result, there is now more interference, the system is less dependable, and there is less room for expansion in the future. Researchers have looked to optical communication technology as a viable alternative for solving these difficulties. Compared to conventional RF-based communication technologies, optical communication technologies, which transfer data via light waves, provide a number of advantages. Visible light communication is a promising optical communication method.

VLC is a type of wireless communication that sends data by visible light. The fundamental idea behind VLC is to transfer data by modulating the amount of light that is emitted from a light source, such as an LED (light emitting diode). A photodetector, such as a photodiode, then picks up the modulated light and converts it into an electrical signal that a receiver can decode. The use of VLC for indoor positioning has become one of the technology's most promising use cases. Determine the location of a person or object inside a building or other enclosed place using indoor positioning systems (IPS). As the signals from GPS satellites cannot pass through structures or other impediments, GPS (the global positioning system) is not ideal for interior positioning. Although RF-based IPS systems have been created, they are nevertheless constrained by the same issues as other RF-based communication technologies.

The IPS systems are mainly categorized into three parts which are VLC transmitters, VLC Receivers and VLC Channels. Devices called VLC transmitters use light to send data wirelessly. These transmitters emit light from LEDs, and the brightness of the light contains data that is encoded. Compared to more established wireless communication methods like Wi-Fi or Bluetooth, VLC technology offers a number of benefits. First off, it can be utilized in places where conventional wireless communication technologies are impractical, such hospital rooms or airplane cabins. Receivers for Visible Light Communication are tools that are able to identify and decode signals sent by visible light waves. VLC is a new technology that transmits information quickly and securely using light waves as an alternative to conventional wireless communication techniques. High-speed data transfer, indoor navigation, and automobile communication are just a few of the uses for VLC receivers. The ability of VLC receivers to broadcast and receive data using existing lighting infrastructure, such as LED bulbs, is one of their main advantages. And the term" VLC channels" refers to the many pathways or channels available for employing visible light wavelengths to transfer data. The number of channels that can be used simultaneously to improve the amount of data that can be communicated depends on the frequency range or color of light that each channel corresponds to. A number of variables, including the accessibility of light sources and the capability of the receivers, affect the number of channels that are available and the amount of data that can be communicated on each channel. Numerous applications, such as indoor location, highspeed data transfer, and automobile communication, are able of using VLC channels.

The data transmission modulation method used by VLC is one of its key characteristics. The data transmission modulation method used by VLC is one of its key characteristics. Pulse Amplitude Modulation (PAM), Code Shift Keying (CSK), and Pulse Width Modulation (PWM) are the three main modulation methods used in VLC. The simplest modulation method, known as AM, includes changing the light signal's amplitude to represent digital data. Another well-liked modulation method in VLC is FM, which modifies the light signal's frequency to symbolize data. PWM is a more advanced modulation method that

transmits data by modulating the pulse width of the light stream. Due to its ease of use and lack of intricacy, AM is frequently used in VLC. AM modulation works well for low-speed uses like indoor positioning and lighting control. However, AM is spectrally inefficient and susceptible to disturbance from outside light sources. Another common modulation method in VLC is FM, which has higher spectral effectiveness than AM. For high-speed data transmission applications like video streaming and data-intensive activities, FM modulation is a good fit. However, FM is prone to interference from ambient light sources and needs a high signal-to-noise ratio (SNR) to attain high data rate. With its high spectral efficiency and suitability for high-speed data transmission uses, PWM is a more sophisticated modulation method used in VLC. Researchers have also suggested other modulation methods in addition to these ones, including Spread Spectrum Modulation (SSM), Orthogonal Frequency Division Multiplexing (OFDM), and Pulse Position Modulation (PPM) for VLC. SSM is a type of modulation that disperses the information over a broad frequency range to boost SNR and lessen interference. In order to achieve high spectral efficiency, OFDM is a multi-carrier modulation method that splits the signal into numerous sub-carriers. PPM is a type of modulation that transmits data by modulating the pulse's location in the time domain. A common modulation method used in VLC devices is On-Off Keying (OOK) modulation. OOK modulation is a straightforward and uncomplicated modulation method used in VLC. To represent binary 1s and 0s, it entails turning on and off the light source. OOK modulation is frequently used in VLC because it is straightforward and inexpensive to apply. Low-speed applications like indoor positioning and lighting management can benefit from OOK modulation. In conclusion, modification techniques are essential to the effectiveness of VLC. Depending on application requirements like data rate, SNR, and interference, a modulation method is chosen.

In recent researchers and studies, they've found and developed various techniques to develop indoor positioning systems using visible light, some of the mainly used methods are time difference of arrival (TDoA), angle of arrival (AoA), Proximity Approach and Received signal strengths (RSS). By measuring the time difference of arrival (TDoA) or angle of arrival (AoA) of the VLC signals the mobile device receives, VLC-based IPS devices can provide precise positioning data. The drawbacks for the TDOA are due to its dependency of accurate and synchronized clocks for each sensor. angle-based positioning. In angle-based positioning, a collection of photodetectors is used to measure the angle of arrival (AoA) of the VLC signals. This method provides extremely accurate positioning data, but it also necessitates a large number of photodetectors, which can raise the system's expense and complexity. The multipath effect of the VLC signals, which can result in signal reflections and diffractions, can also reduce the precision of angle-based positioning. A proximity approach A specific number of LED lights that serve as beacons transmit an individual ID signal indicating their location across the illumination beam. This happens when a person in the path of one of the light beams is carrying a mobile device with a cheap detector connected to it. However, this system's accuracy is poor because it only displays one co-ordinate (location) throughout the whole region of a single LED beacon. Another flaw in this approach is it is unable to allow the light cones emitted by nearby beacons to overlap. In Received signal strength method LEDs with unique IDs placed and the location of the user is found by the transmitter with the highest RSS, location of the user is indicated as the closest to the highest RSS indicating LED (coordinates of LEDs are pre known). However, if the noise level is high, it can result in in degraded performance signal strength indicator decreasing the accuracy of the system. Trilateration and multi-lateration is another technique that use RSS values, depends completely on the current RSS values – (online) and ultimately measures the receiver and the respective transmitter's distance. The receiver is identified to be located at the point of intersection of all the three circles centered at their respective transmitters.

In this paper a novel indoor positioning system using a hybrid approach of Received signal strength (RSS) and fingerprinting method is proposed. By encoding unique IDs for the LEDs and dividing the area considered into small parts and calculating the necessary values according to the divided parts. In fingerprinting method an online and offline base phase is used. The data transmitted by the LEDs using OOK modulation is received from the photodiode. Photodiode receive the signals and decode the IDs and record signal strengths received by the LEDs and goes to the positioning algorithm, in this algorithm the it will compare the RSS values and the position will be displayed according to the values of the fingerprinted grid. Moreover, the hardware implementation and increasing of the accuracy of the system by increasing the number of transmitters is also the milestones approached from this research.

The remainder of this paper is organized as follows. Section II presents the system model of VLC system; importance of the components system and their significance is also discussed. Then the proposed indoor positioning system using the RSS and fingerprinting hybrid approach is introduces in section III. In Section IV, the experimental demonstration results are presented. Finally, conclusions are drawn in Section V.

II. System Model

This section will give a brief introduction of the VLC positioning system using RSS method, Data transmission and data receiving and the positioning algorithms. Modulation method for the VLC-based positioning is also investigated.

A. VLC Positioning system using Received signal strength

Fig. 1. represents the basic working of a VLC positioning system using received signal strength (RSS) which consist of mainly three parts which is the transmitter, receiver and the positioning algorithm. And the working of the whole can be summarized into data encoding, data transmission, data receiving, data demodulation and finally the demodulated data will be recorded and passed to the algorithm which determines the position of a user or an object which is inside an indoor area by identifying the LED IDs and the RSS power received by the receiver.[1]

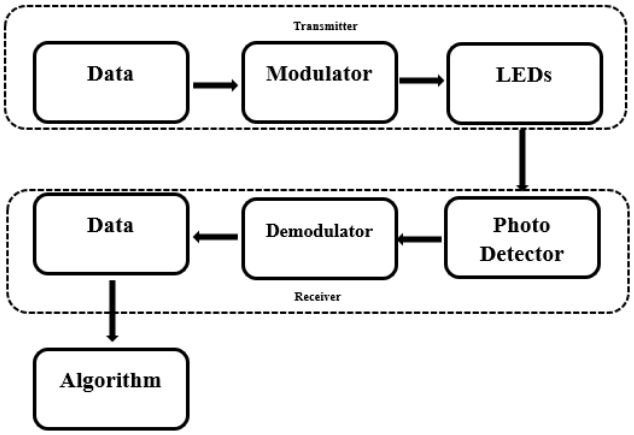

Figure 1 Basic Working of VLC System using RSS

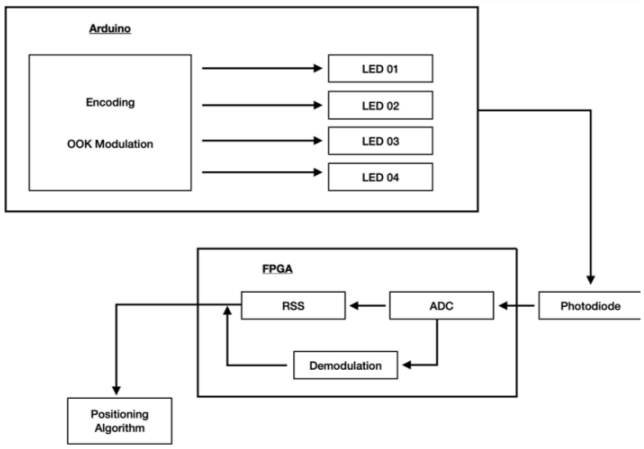

Figure 2 Proposed VLC IPS system

B. Data Transmision

In VLC systems the data transmitted through LEDs in most of the cases power LEDs are used since it is required higher intensity values and differences to determine the necessary data at the receiver end. To identify the LEDs a specific unique ID is given for each and every one. To create this ID the ON-OFF keying (OOK) modulation is used. When the LED is ON the binary number that transmit is '1' and when it is off the binary number that transmit is '0'. Accordingly, a unique ID represents all the LEDs of the system.

C. Data Receiving

The data transmitted through the LEDs are received by a photodiode. Here the bit streams of different LEDs are recorded and the received signal strengths of all LEDs are measured. According to the surrounding that uses this system a threshold value is calculated to identify the bits '0' and '1'. For example, if the threshold value is 80 the intensity values less than 80 is identified as '0' and the intensity values greater than 80 is identified as '1'. When the intensity level is in higher state the received signal strength is also recorded. And these data will be transferred for the positioning Algorithm.

D. Positioning Algorithm

The data received by the receiver is recorded and identified through this algorithm. Which is developed to identify the position of the for example of 3 LEDs are used the IDs of these 3 LEDs are identified as ID number A, B and C. And the intensities of the LEDs are recorded as X, Y and Z. The intensity values of the ID numbers are compared and position is calculated.[2]

III. PROPOSED INDOOR POSITIONING SCHEME

A. Implementation

The aim of this research is developing and implementing a unique and novel indoor positioning system, which uses VLC and a hybrid strategy of RSS and fingerprinting approaches, which can greatly increase the location accuracy. This system is a unidirectional communication system with a photodiode receiver and three LEDs acting as transmitters. For encoding and modulating the ID signals, the LEDs should be connected to Arduino, and the photodiode receiver should be connected to FPGA.

The last stage is to create the software that will direct the Arduino to produce distinct ID signals and time delays for each LED. In order to separate the ID signals from the incoming optical pulses, the software must also contain the demodulation and decoding algorithms. This developed software will be used to analyze the information obtained from the LEDs and to locate the photodiode receiver.

The final goal in this implementation strategy is signal processing. To measure the received signal levels of each LED signal and determine the matching IDs, signal processing methods are required. This data is saved and will be used for fingerprinting and RSS based location. Taking fingerprints is the fourth stage. By measuring the received signal levels and their corresponding positions within the indoor environment, reference signal data is gathered. To construct a reference database for fingerprinting, this information is used. Fingerprinting is a method for locating an object or device based on the distinctive pattern of signals present there.

The measured signal strengths are utilized to compare the RSS values of all the LEDs signals transmitted. Positioning based on fingerprint analysis is the sixth phase. Using fingerprinting techniques, the recorded signal levels are matched to reference signal data to pinpoint the position of the photodiode receiver. Hybrid placement is the sixth phase. The positioning results using fingerprinting and RSS are combined to increase location accuracy. Better accuracy can be achieved using this hybrid approach than using either technique separately.

Finally testing and evaluation is done. The system is put to the test in a controlled indoor setting in order to assess the performance and accuracy of the suggested algorithm. The effectiveness of the system is then evaluated by comparison when number of LEDs increased.

In VLC, data is sent via communicating information through variations in the optical pulse's temporal intensity. Direct detection and intensity modulation (IM) are used for the modulation and demodulation processes (DD). Therefore, the same method is used in the proposed system where the encoding and modulating of LEDs are done by Arduino and the ID signals are received by the photodiode receiver. The signals are then demodulated and decoded and goes through the positioning algorithm which will be used to indicate the location of the photodiode receiver and decoded by FPGA. In this system data is transferred through 4 LEDs where

each LED is given with 4 unique ID signals which means all 4 is given with 8 bits to send with a time delay. The 1st LED send the bitstream and then after some time delay, the second LED start to send the bit stream and so on the this occurs repeatedly as shown in the flow chart in the Fig 3.

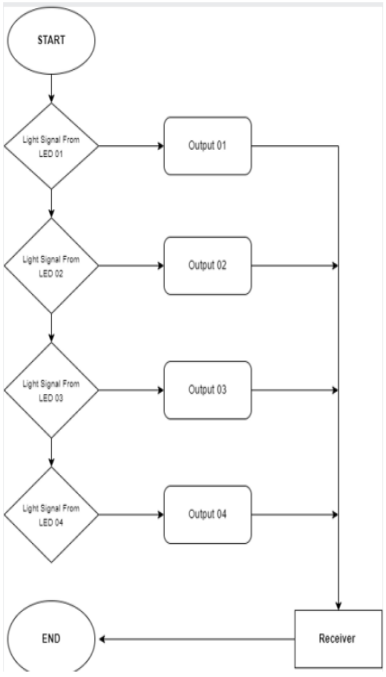

Figure 3 Flow of data in the transmitter

The LEDs are located on the ceiling of a room and the room floor is the considered area of calculating the user's position.

In this system a fingerprinting algorithm is used to determine the location based on the information that is received. Fingerprinting means dividing the area considered into small parts and calculating the necessary values according to the divided parts. In fingerprinting method an online and offline base phase is used. In offline based method a predetermined grid with the coordinates of the room, the ID signals and received signal strengths are stored respectively. In online based method the information of the received signal IDs and signal strengths are processed, compared with the offline grid and indicate the location of the user that is in the same range of the respective coordinate. In this case first only 2 LEDs are considered and two received signal strengths are calculated.[3]

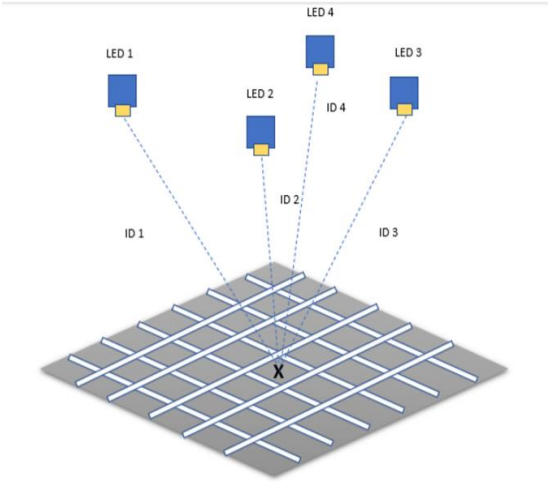

Figure 4 Placing of the Hardware of the system and the fingerprinted grid

This method process data in two ways which are the online based and offline based calculations

Offline grid- Coordinates – X (X can be located anywhere in the fingerprinted grid)

LED 1 signal- RSS range 1

LED 2 signal- RSS range 2

Online processing- If the user is in the location X, the values obtained by online- 1st ID SIGNAL and 2nd ID signal are compared with the offline grid and location is indicated.

If the RSS values are within the range of a certain coordinate, for example if the RSS values are obtained online are satisfied by all the two in the above-mentioned RSS range 1 and RSS range 2 the position of the photodiode receiver(user) will be indicated as X.

To increase the accuracy further the number of transmitters is increased to 4 and the number of parts in the grid will be increased.

Offline grid- Coordinates – (X)

LED 1 signal- RSS range 1

LED 2 signal- RSS range 2

LED 3 signal-RSS range 3

LED 4 signal- RSS range 4

Online calculation

LED 1 signal- RSS value 1

LED 2 signal- RSS value 2

LED 3 signal-RSS value 3

LED 4 signal- RSS value 4

Finding Coordinates by comparing with the offline grid.

B. Transmitter

First the system was developed only by using Arduino boards. In the initial prototype, the transmitter delays the transmission of two distinct bit streams through two LEDs. The receiver records the data streams and determines the two LEDs' intensities. This is accomplished by connecting the photodiode to the analog input pin of an Arduino Nano, which serves as the receiver. The Arduino code is set up to recognize the signal intensities and translate them into binary numbers. The intensity levels above 90 are identified as bit 1, the intensity levels below 60 are identified as bit 0, and the intensity levels between 60 and 90 are identified as the PWM wave that is received before starting to send the bit stream of each LED. This is because the transmission modulation scheme is on-off keying (OOK). The receiver

can precisely decode the information and identify the LED and its associated bit stream thanks to this way of information encoding. The photo diode receiver measures the signal intensities and maps them into integer values between 0 and 1023 using the analog read function. The threshold values of the LED are calculated in the code to identify the intensity values that indicate a value less than 60 as bit 0, intensity values that are higher than 90 as bit 1, and the intensity values between 60 and 90 as the signal that will be the identification of the beginning of receiving the bit streams. The ID of the bit stream is given together with the intensity levels of the received signals after the intensity values of the signals have been recognized and converted into binary values. The positioning algorithm uses this data to precisely determine the location of the photo diode receiver. This system is then final developed up to 4 LEDs (Transmitters).[4]

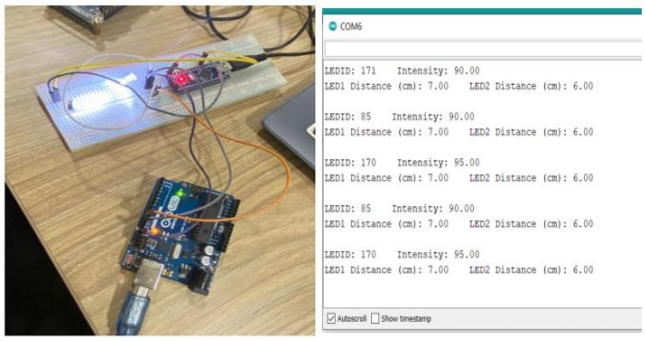

Figure 5 First Prototype and testing results

C. Receiver

In the initial prototype, the transmitter delays the transmission of two distinct bit streams through two LEDs. The receiver records the data streams and determines the two LEDs' intensities. This is accomplished by connecting the photodiode to the analog input pin of an Arduino Nano, which serves as the receiver. The Arduino code is set up to recognize the signal intensities and translate them into binary numbers.

Initially, the algorithm was created to work with two LEDs and two grid components. The breadboard is partitioned into portions A and B to test the precision of our implementation. According to the illustration, the side of LED 1 was given the designation side A, and the side of LED 2 was given the designation side B. The photodiode receives light from both of the LEDs when it is positioned on either side of the breadboard. The location of the photodiode is then determined by calculating the received intensities of the two LEDs and comparing them. This method allowed us to verify the precision of our algorithm and make sure it operated as planned before expanding it to a bigger grid with more LEDs and photodiodes.

Figure 6 First prototype position indication

Then for the final system the receiver is developed using FPGA since it has a high processing speed compared to others and later it can be utilized to develop the receiver device that can be used to this type of VLC indoor positioning systems.

The data from the photodiodes would be received and processed by a module built for the FPGA board. The module recognized the LEDs' IDs and compared the intensities of each one. Using a look-up table, the received intensity values were then assigned to the appropriate LED. It was able to locate the receiver by comparing the intensity values of the four LEDs. Then a testbench was developed that mimicked the transmission and reception of the four LEDs in order to evaluate the operation of our application. The necessary data was produced by the testbench and transmitted to the FPGA board. The program's ability to recognize the IDs of the LEDs and precisely determine the receiver's position was then confirmed. Overall, our algorithm was successful at recognizing the IDs and comparing the values of the four LEDs' intensities to identify where the receiver was located inside the building. The software on the Altera DE0 Nano FPGA board was a crucial aspect of our indoor positioning system that used visible light communications for this.

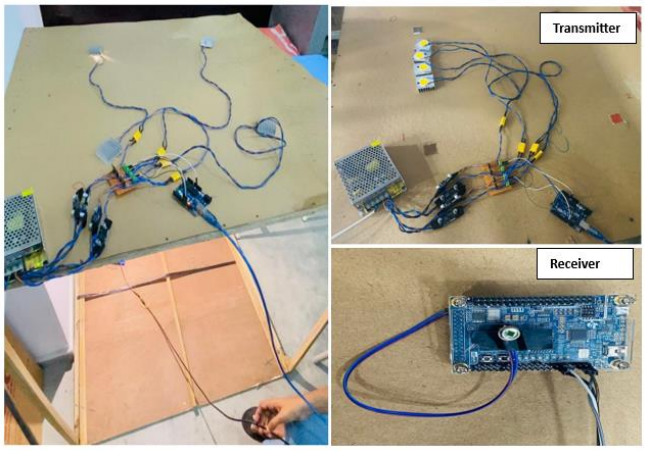

Figure 7 Final Hardware Setup

The figure shows the hardware setup which imitates an indoor environment. And transmitter and receiver components were housed inside the frame, which also served as a controlled environment for system testing.[5]

D. Indicating Software

For the user to identify the location clearly and easily an indicating software with a user-friendly interface is created. It utilized a C sharp Windows Forms Application created in Microsoft Visual Studio to create the indicating program. It communicates via a serial port and will identify the position as shown in the based on the data received. A few variables are initialized, a Serial Port object is created, and an event handler is put up for the Serial Port object's Data Received event. Data is added to a Queue object when it is received from the serial port. The timer event (tmrMain Tick), which occurs every 200 milliseconds, then processes the Queue object. Data that is in the queue is dequeued and handled one byte at a time. In order to identify whether a new position value is being delivered, the algorithm scans for a certain byte pattern . A method is called to update the position and redraw the position indication on the form when a position

value is received. A method to deliver data over the serial port is also included in the code, along with event handlers for the form load and button click events.

Figure 8 User Interface of the indicating Software

As shown in the figure the position of the receiver will be shown in the shaded region. The intensity values of the LEDs are also available to read to the user in this app.

IV. EXPREMIMENTAL RESULTS

A single transmitter and receiver were used in the first experiment to test the system's accuracy at a basic level. The signal intensity was measured at each location while the transmitter and receiver were positioned at predetermined separations from one another. Using this information, a signal strength map was made, which was later used to deter mine where the receiver was located in the room. In the second experiment, the system was tested with several transmitters and receivers in order to assess its performance in circumstances that were more like real-world usage. The signal strength was tested at each receiver site after transmitters were positioned at various points across the room. Then this data is used to create the fingerprinted grid to create the grid I the considered floor area.

In each experiment, the estimated position and the actual position of the receiver were compared to determine how accurate the system was. The outcomes of these tests demonstrated that even in intricate inside situations, the indoor positioning system using visible light communication was capable of achieving high levels of accuracy. It was discovered that the RRS approach was very successful, particularly when used alongside fingerprinting. Higher accuracy levels were achieved by increasing the number of transmitters (LEDs) and by improving the fingerprinted grid. Overall, the experimental findings showed how visible light communication might be used for indoor positioning and emphasized the need for thorough system optimization for particular settings and application scenarios. These results offer important information for further study in this area and raise intriguing ideas for the creation of highly accurate indoor positioning systems.

First started by calculating the current generated on the photo diode in relation to distance. A number of experiments were carried out to determine the current generated on the photo diode in relation to the distance between the LED and the photo diode. The current generated on the photo diode was first measured when the LED and photo diode were placed at a fixed distance. Then, the experiment once again is c conducted, gradually extending the distance between the LED and the photo diode while monitoring the current generated on the photo diode. It was able to see a direct relationship between the distance between the LED and the photo diode and the current generated on the photo diode by graphing the data points. The LED-to-photo diode connection in the indoor positioning system that uses visible light communication was then calibrated using these data.

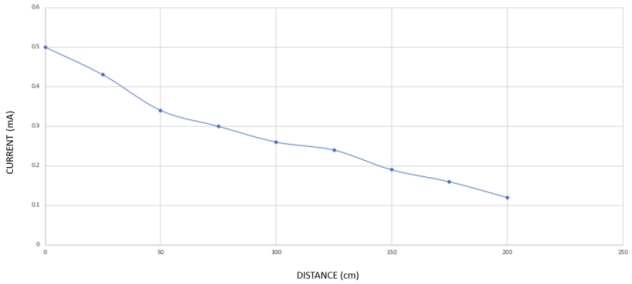

Figure 9 Current produced on the photo diode with the Distance Plot

Obtaining the LED thresholds was a crucial step in the implementation of the indoor positioning system using Arduino. This was required in order to recognize the bit streams being delivered to the photo diode. First, the LEDs are connected to the Arduino digital output pins and sent bit streams of various sizes in order to determine the thresholds. Then, using the analog Read() function, the photo diode to the Arduino's analog input pin and read the voltage readings. This procedure was performed at distances ranging from 0 cm to 20 cm between the LEDs and the photo diode. Next, a graph is created by plotting the voltage values against the separation between the LED and photo diode. The threshold voltage at which the LED could be consistently detected by the photo diode could be determined from the graph. In the next studies, the bit streams were detected using this threshold voltage as a reference. It was able to make sure that the system could precisely locate the receiver (photo diode) and detect the bit streams by acquiring the LEDs' threshold values. This was a crucial stage in the creation of the indoor positioning system since it set the stage for the later tests that were run to gauge the system's effectiveness.

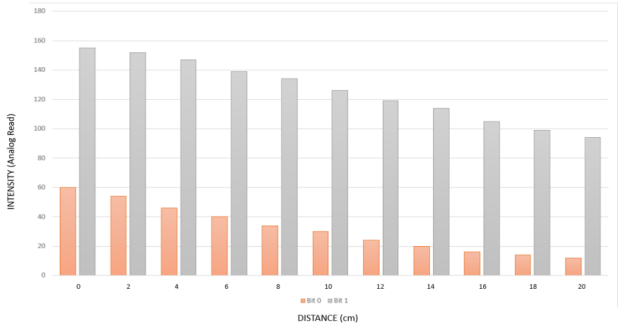

Figure 10 Plot of the intensity values with the distance when bit 0 and bit 1 is sent

known bit streams (10101010, 01010101, 10100101, and 01011010) from the LEDs were sent in order to measure the bit error rate (BER) at various locations along the borders of the fingerprinted grid, and the Arduino recorded the received bit streams at the photo diode. The BER was then determined by comparing the sent and received bit streams. Five spots were taken into consideration along the four-part, 1 m x 1 m fingerprinted grid's perimeter. When the bit streams for 10101010, 01010101, 10100101, and 01011010 were transferred, the computed BER was 5.625 percent. An essential indicator for assessing the effectiveness of a communication system is the BER. A communication system is more dependable when its BER is lower. The generated

BER can be used to assess the indoor positioning system's efficacy and boost its accuracy.

By using the various bit streams as the x-axis and the related BER values as the y-axis of a bar graph, data can be visualized this data. At each of the five locations around the edges of the fingerprinted grid, It can be visualize the BER values for each bit stream. This graph can be used to compare the performance of the system at various points and can be used to spot trends or patterns in the BER values.

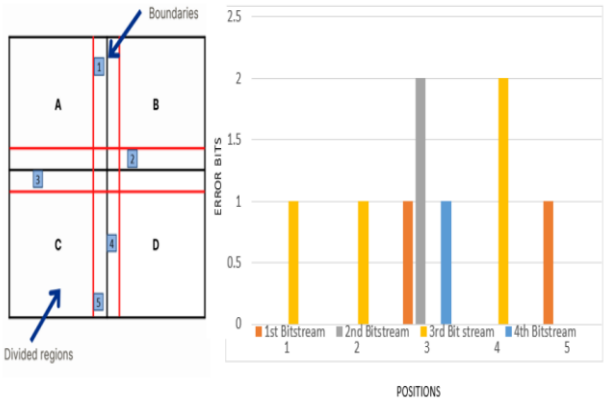

Figure 11 Errored number of Bits in different Positions

Table 1 Accuracy of the system when using 2 LEDs and 4 LEDs

	Position	2 LEDs	4 LEDs
A	A1	87.5%	94%
	A2	69%	100%
	A3	87.5%	100%
	A4	75%	94%
B	B1	94%	100%
	B2	75%	94%
	B3	81%	100%
	B4	62.5%	84.5%
C	C1	87.5%	94%
	C2	87.5%	100%
	C3	81%	84.5%
	C4	81%	100%
D	D1	81%	84.5%
	D2	75%	84.5%
	D3	94%	100%
	D4	69%	100%

Table 1 presents the accuracy comparison of the indoor positioning system within a specified area divided into 16 equal parts (as shown in Figure 12). In this setup, two configurations were evaluated separately: one using 2 LEDs and the other using 4 LEDs. For each configuration, accuracy was calculated by measuring the system's precision in each of the 16 parts, and then converting these values into percentages. When the system utilized 2 LEDs, an overall accuracy of 80.47% was achieved, whereas increasing the number of LEDs to 4 improved the accuracy significantly to 94.625%. This comparative analysis underscores the impact of the LED quantity on positioning precision, demonstrating that additional LEDs enhance system accuracy across the divided area.

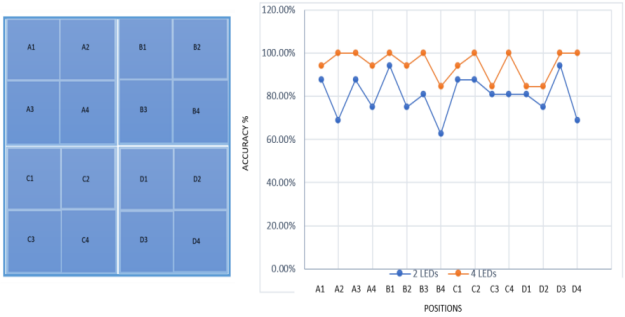

Figure 12 Plot of the average accuracy of positions

Overall, our findings shown that adding more LEDs can considerably increase the precision of location indication in our indoor positioning system based on visible light communication. This may have significant ramifications for a variety of applications that depend on precise indoor positioning, like asset monitoring and navigation systems.

V. CONCLUSION

In this paper an indoor positioning system which uses a novel hybrid technique of combined of RRS and Fingerprinting method is discussed. The positioning system is theoretically and physically demonstrated and tested for the accuracy and the reliability. And successfully investigated on increasing the accuracy of the system by changing variables and obtaining the experimental readings. This system can be developed further by using a machine learning algorithm for fingerprinting. This could entail applying machine learning strategies to automatically recognize and categorize patterns in the received signal strength data, which could ultimately improve the indoor positioning system's accuracy and dependability.

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REFERENCES

[1] J. C. Torres, A. Montes, S. L. Mendoza, P. R. Fernandez, J. S. Betancourt, L. Escandell, C. I. Del Valle, and J. M. S´anchez-Pena, "A low-cost visible light positioning system for indoor positioning," Sensors, vol. 20, no. 18, p. 5145, 2020.

[2] H. Zou, L. Xie, Q.-S. Jia, and H. Wang, "Platform and algorithm development for a rfid-based indoor positioning system," Unmanned Systems, vol. 2, no. 03, pp. 279– 291, 2014.

[3] D. P. O. S. B. O. W. J. O. M. I. O. Z. G. O. a. R. O. Yousef Almadani 1, ORCID, "Visible light communications for industrial applications—challenges and potentials," 2020.

[4] K. A. G Madhuri and R. S. Prabha, "Transmission of data, audio and text signal using li-fi technology," 2020.

[5] S. B. M. I. L. M. D. Plets, Y. Almadani and W. Joseph, ""efficient 3d trilateration algorithm for visible light positioning," Journal of Optics, vol. 21, p. 1

Dependence of Electrolyte Medium to Performance of Reduced Graphene Oxide (R-GO) based Supercapacitor

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Abstract*— Supercapacitors (SCs) play a crucial role in energy storage applications. SCs store and release energy by maintaining an electrostatic charge at the interface between the electrode and an electrolyte solution. Key advantages of SCs include their high capacitance, long cycle life and high power density. However, they typically have lower energy density compared to traditional batteries. Reduced graphene oxide (R-GO) is a highly significant electrode material for SCs due to its unique combination of properties such as high electrical conductivity, large surface area, chemical stability and easy functionalization that enhance the performance of SCs. The electrolyte is responsible for facilitating the movement of ions between the electrodes during the charging and discharging cycles. In this study, R-GO was synthesized from natural graphite using the modified Hummers method. The process began with the oxidation of graphite powder using a mixture of oxidizing agents, 98% concentrated sulfuric acid (H_2SO_4) and potassium permanganate and sodium nitrate. A reducing agent, hydrogen peroxide was employed to chemically reduce the GO. Creating an electrode for the SC was begun by dispersing R-GO in dimethylformamide (DMF). Titanium dioxide (TiO_2) was used as binder. R-GO/TiO_2 suspension was coated onto a conductive substrate, fluorine-doped tin oxide (FTO). Upon deposition, the DMF solvent was evaporated, leaving behind a well-structured R-GO layer on the substrate. 2M H_2SO_4 and Lithium trifluoromethenesulfonate ($LiCF_3SO_3$) were used as electrolytes separately. This study explores the performance of SCs utilizing acidic electrolytes in comparison to ionic liquid electrolytes. This research reveals that R-GO based SCs exhibit the highest specific capacitance values of 146 F g^{-1} and 59 F g^{-1} at 2 mV s^{-1} with H_2SO_4 and $LiCF_3SO_3$ electrolytes respectively. Moreover, the study demonstrates the maximum energy density is 17.07 Wh kg^{-1} and 2.39 Wh kg^{-1} at 0.5 mA current for acidic and ionic liquid electrolytes respectively, emphasizing their capability to deliver and absorb energy. The study also shows the maximum power density 17.57 kW kg^{-1} achieved with ionic liquid electrolyte and 81.5 kW kg^{-1} with acidic electrolyte at 5 mA. In conclusion, this abstract underscores the pivotal role of electrolyte selection in determining the performance of R-GO based SCs. Additionally, the study reveals that R-GO-based SC shows higher performance with acidic electrolytes.

Keywords*— *supercapacitor, electrolyte, reduced graphene oxide, ionic liquid, energy density, specific capacitance

I. INTRODUCTION

Supercapacitors (SCs) hold significant importance as energy storage devices due to their unique combination of characteristics. Their high power density, fast charging and discharging capabilities, long cycle life, low maintenance requirements, safety and environmental friendliness make them stand out in comparison to other energy storage technologies [1]. This versatility renders SCs suitable for a wide range of applications, including regenerative braking systems in vehicles, grid stabilization, backup power systems and portable electronics [2]. Compared to other energy storage devices, such as batteries, the main drawback of SCs is their relatively lower energy density. The electrode material plays a pivotal role in determining the performance and efficiency of SCs. Optimizing electrode materials through advancements in material science and engineering is crucial for enhancing the energy density of SCs [3,4]. R-GO holds significant importance as an electrode material for SCs due to its unique combination of properties. R-GO offers high specific surface area, excellent electrical conductivity, and exceptional mechanical flexibility, making it an ideal candidate for enhancing the energy storage capacity of SCs [5]. Moreover, the facile synthesis of R-GO from graphene oxide (GO) precursor via simple reduction methods ensures scalability and cost-effectiveness for large-scale production. These attributes make R-GO a promising electrode material for next-generation SCs [6]. The modified Hummers method for synthesizing R-GO from graphite powder holds significant importance in the realm of graphene-based materials synthesis. This method offers several advantages, including simplicity, scalability, and cost-effectiveness [7]. By leveraging a combination of strong oxidizing agents and acidic conditions, the modified Hummers method efficiently exfoliates graphite layers and introduces oxygen-containing functional groups onto the graphene sheets, leading to the formation of GO [8]. Subsequent reduction of GO to R-GO, typically achieved through chemical or thermal means, results in the restoration of sp^2 carbon network and improved electrical conductivity while maintaining the oxygen functionalities [9]. The electrolyte medium in SCs serves a crucial role in facilitating the ion transport between the electrodes, thereby enabling the storage and release of electrical energy. The selection of electrolyte significantly impacts the performance and efficiency of SCs [10]. Ionic conductivity, viscosity, and stability are key factors that influence the electrolyte's ability to support rapid charge/discharge rates and maintain long-term cycling stability. Furthermore, electrolytes also influence the device's energy density and power density [11]. The H_2SO_4 solutions, provide high ionic conductivity, facilitating efficient ion transport between the electrodes. This results in enhanced charge/discharge rates, specific capacitance and improved power delivery capabilities of the SCs [12]. Moreover, acidic electrolytes are often cost-effective and readily available, making them practical for large-scale production and

commercial applications. Ionic liquids (ILs) have emerged as promising electrolytes for SCs due to their unique properties and advantages [13]. ILs offer wide electrochemical stability windows, allowing for operation at higher voltages without the risk of electrolyte decomposition, negligible vapor pressure, high thermal stability, and non-flammability [14]. These characteristics enable the utilization of electrode materials with higher capacitance and facilitate the development of high-energy-density SCs [15]. In this study, R-GO was synthesized from graphite powder using the modified Hummers method and investigated its performance as an electrode material for SCs. The electrochemical performance of R-GO-based SCs was symmetrically examined utilizing two different types of electrolytes: acidic electrolyte and IL electrolyte. 2M H_2SO_4 solution and $LiCF_3SO_3$ were used as acidic the electrolyte and the IL electrolyte separately. By comparing the performance of R-GO-based SCs with these two different electrolytes. The aim was to gain insights into the influence of electrolyte type on the overall electrochemical performance and energy storage characteristics of SCs, thereby contributing to the advancement of SC technology for various practical applications.

II. METHODOLOGY

A. Synthesis of Reduced Graphene Oxide

R-GO was synthesized by modified Hummer's method. 26 mL of 98% sulfuric acid was slowly added to the mixture of 2 g of natural graphite and 1 g of sodium nitrate in an ice bath while the mixture was stirred using a magnetic stirrer. Then 6 g of potassium permanganate was added, slowly. The mixture was kept overnight for oxidation. Then, the mixture was diluted to 400 mL and 30% hydrogen peroxide was added slowly to quench excess potassium permanganate. The resulting greenish – yellow suspension was filtered and the dilution procedure was repeated for the above suspension to obtain R-GO suspension.

B. Fabrication of Electrode

The pH value of the suspension R-GO 100 ml (1 g L^{-1}) was tuned to 10 by gradually adding sodium hydroxide. Then the mixture was heated to 95 ℃ and held for 2 h and it was sonicated for 30 minutes. Then the mixture was filtered and dried at 65 ℃ for 12 h in a vacuum oven. The 0.200 g of RGO was mixed with 2 mL of DMF. Then, 0.04 g of TiO_2 (20% of R-GO) was added and the solution was sonicated for 3 h and then stirred for 24 h to reduce the particle size of R-GO.

C. Electrode Preparation

The slurry was then coated uniformly on fluorine doped tin oxide coated glass (FTO) current collector substrate using the drop cast method. The coated electrode was dried at 120 ℃ for 1 h to remove the solvent.

D. Cell Assembling

After preparing two identical electrodes, cells were assembled sandwiching the electrolyte – impregnated filter paper which also works as the separator. The entire stack was then sealed to prevent electrolyte leakage.

E. Electrolyte preparation

2M H_2SO_4 solution was prepared by diluting 98% concentrated sulfuric acid. $LiCF_3SO_3$ ionic liquid electrolyte was prepared by mixing ethylene carbonate and propylene carbonate in 1:1 molar ratio. The electrolyte was further enhanced by dissolving an ionic compound into the mixture until saturation was achieved.

F. Electrochemical testing

Cyclic Voltammetry (CV) was performed between 0 – 1 V at different scan rates 2 mV s^{-1} to 100 mV s^{-1} at room temperature. In galvanostatic charge – discharge (GCD) testing, the SC was charged and discharged at a constant current and the voltage across the electrodes was monitored. GCD testing was done at different constant currents 0.5 mA to 5 mA. Electrochemical Impedance Spectroscopy (EIS) was done using a sinusoidal signal with an amplitude of 10 mV in the frequency range of 0.1 Hz to 10^5 Hz.

G. Characterization

In this study, X-ray diffraction (XRD) analysis was conducted on graphite, GO and R-GO powders as well as on synthesized thin film to investigate their crystalline structure. XRD measurements were performed using a Rigaku SmartLab X-ray diffractometer with a scanning rate 10° per minute in a 2θ range from 0° to 100° with Cu-Kα radiation (λ = 0.1546 nm, 40 kV and 30 mA).

III. RESULTS AND DISCUSSION

A. Material characterization

XRD data analysis was conducted on graphite, GO and R-GO powder samples to study the crystalline structures of powders using XRD (Fig. 1). Graphite, characterized by its well-ordered hexagonal lattice structure, exhibited a sharp diffraction peak at 2θ = 26.48° corresponding to its (002) crystallographic planes, indicative of its high degree of crystallinity and layered arrangement [16]. In contrast, GO powder displayed a broadened and less intense diffraction pattern at 2θ = 11.38° which can attribute to the presence of oxygen-containing functional groups disrupting the ordered carbon lattice and leading to increased disorder and interlayer spacing as given in Table I [17,18]. Upon reduction to R-GO, the diffraction peaks were shifted to 2θ = 26.64° and broadened, resembling those of graphite, suggesting partial restoration of the graphene-like structure. However, the reduced interlayer spacing of certain peaks indicated incomplete restoration and residual disorder compared to pristine graphite [19]. These findings underscore the structural evolution induced by the oxidation and reduction processes, elucidating the impact of functionalization and restoration on the crystallinity and interlayer spacing of graphene-based materials. Estimation of *d* (spacing between

adjacent crystal planes), *D* (average crystalline size), *L* (plane crystalline size) and *n* (number of graphene layers per region) using the following equations [20,21]

$$d = \frac{n\lambda}{2\,Sin\theta} \qquad (1)$$

$$D = \frac{k\lambda}{\beta\,Cos\theta} \qquad (2)$$

$$L = \frac{1.84\lambda}{\beta\,cos\theta} \qquad (3)$$

θ = angle of incident x-rays
n = integer representing the order of diffraction
λ = wavelength of incident x-rays
k = dimensionless shape factor (k = 0.89 for spherical crystals with cubic unit cells)
β = full-width half maximum (FWHM) of the diffraction peak

The reduction of average crystallite size in R-GO relative to GO was noticed. That showed the shrinkage of graphene regions and the foundation of more lateral defects, which was due to the exclusion of graphene layers upon reduction [17].

$$n = \frac{D}{d} + 1 = \frac{2k\,tan\theta}{\beta} + 1 \qquad (4)$$

XRD analysis was employed to investigate the structural characteristics of the R-GO thin film synthesized using DMF and TiO_2 as the solvent and binder respectively (Fig. 1). XRD results revealed a distinctive diffraction peak at 2θ =2 5.89° corresponding to the (002) plane of R-GO, indicative of the successful reduction of GO to RGO [22]. There were some broadened and less intense diffraction peaks at 2θ = 37.17°, 50.99°, 54.30°, 61.05° and 65.05° respectively. Moreover, our findings suggest that DMF-mediated reduction effectively promotes the restoration of sp^2 hybridized carbon networks, leading to the formation of well-defined crystalline structures within the R-GO thin films. This study underscores the significance of solvent selection in tailoring the structural and morphological properties of R-GO thin films for energy storage devices [23,24].

Structural characteristics of graphite, GO and R-GO powders were investigated utilizing Raman spectroscopy. The Raman spectra of graphite exhibited prominent peaks corresponding to the G band (graphitic sp^2 bonded carbon), G band and the relatively weaker 2D band (second-order double resonance process) [25]. In contrast, the Raman spectra of GO displayed a notable increase in the intensity of the D band (defect-induced disorder) due to the introduction of oxygen-containing functional groups during the oxidation process [26]. The intensity of band D depends on the number of defects and oxygen atoms present on GO surface. Additionally, the disappearance of the 2D band and the emergence of the D band provided further evidence of the structural disruption caused by the oxidation of graphite to form GO [27]. Furthermore, the recovery of the 2D band intensity and the narrowing of the G band suggested the restoration of graphitic structure and improved crystallinity in the R-GO sample compared to GO [28]. Therefore, thermal reduction of GO to R-GO provided us with a material having a reduced number of carboxylic acid, ether and hydroxyl groups. Furthermore, G band is also contributed by the presence of stretching C-C bond, which is common in all sp^2 carbon systems [29]. The changes in the structure during the reduction process were analyzed based on D versus G signal intensity. I_D/I_G ratio shows the degree of disorder in this carbon-based material. It can be seen that the intensity ratio (I_D/I_G) is GO is about 0.91 while the value of R-GO is 1.10 may be due to the presence of unrepaired defects that remained after the removal of large amounts of oxygen-containing functional groups [30,31]. On the other hand, the ratio of I_D/I_G is inversely proportional to the average sp^2 cluster size and the higher the (R-GO to GO) ratio is, the better efficiency and build-up in sp^2 surface area can be obtained [32].

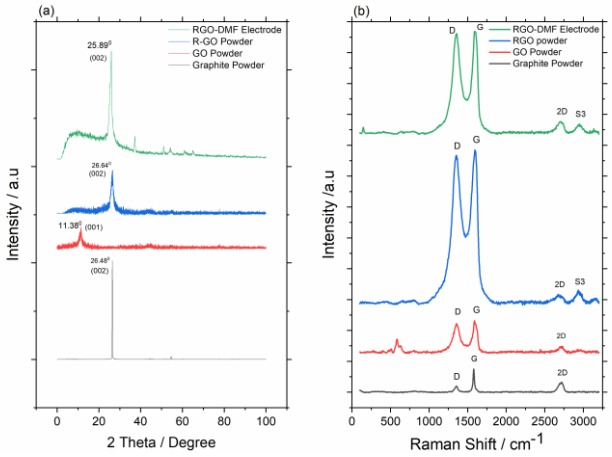

Fig. 1. (a) XRD Spectrums (b) Raman Spectroscopy of graphite powder, GO powder, R-GO powder and RGO-DMF electrode

TABLE I. SEVERAL PHYSICAL PARAMETERS OBSERVED FROM X-RAY DIFFRACTION AND RAMAN SPECTROSCOPY

Sample	Graphite Powder	GO Powder	R-GO Powder	RGO-DMF Thin Film
2θ /degree	26.48	11.38	26.64	25.89
d /nm	0.34	0.78	0.34	0.34
D /nm	30.14	12.87	1.02	0.89
n	124	17	8	11
L /nm	66.31	16.44	3.29	3.19
D-band / cm^{-1}	1359.09	1359.10	1355.85	1356.18
G-band / cm^{-1}	1583.10	1597.64	1594.05	1595.21
I_D/I_G ratio	0.26	0.91	1.10	0.97
Lsp^2 /nm	63.11	18.03	14.91	16.91
L_D /nm	25.38	13.56	12.34	13.14
nD×10^{11} /cm^{-2}	0.89	3.12	3.78	3.33

I_D/I_G ratio is utilized for the estimation of the in-plane size of sp^2 domains (Lsp^2), average defect distance (L_D) and defect density (nD, cm^{-2}) using the following equations [27],

$$Lsp^2 = \frac{560 I_G}{E_L^4 I_D} \qquad (5)$$

$$L_D^2(nm^2) = 2.4 \times 10^{-9} \lambda_L^4 \frac{I_G}{I_D} \qquad (6)$$

$$nD = \frac{2.4 \times 10^{22}\, I_D}{\lambda_L^4\ \ I_G} \qquad (7)$$

Where E_L=2.417 eV and λ_L=514 nm are the energy and wavelength of the laser source. The calculated I_D/I_G ratio and calculated values for both in and out planes of the crystallite size (i.e., *D* and *L* values) displayed that R-GO has more sp^2 domains formed that are in small size as compared to GO. Accordingly, the calculated nD was found to be larger in R-GO which is evident in the development of more defects. R-GO has more number of sp^2 domains formed which are smaller in size compared to GO [33]. Raman spectroscopy was conducted to study the structure of R-GO thin films synthesized using DMF as the solvent. The results demonstrated that the R-GO thin films exhibited a significant increase in the intensity ratio of the D band to the G band, suggesting a reduction in structural defects and an enhancement in graphitic ordering compared to GO [34]. Moreover, the 2D band exhibited a higher intensity and narrower FWHM in the R-GO thin films, indicating the restoration of sp^2 hybridized carbon networks and improved crystallinity. These findings underscore the effectiveness of DMF as a solvent in promoting the reduction of GO and the formation of high-quality R-GO thin films with enhanced structural integrity and conductivity [9].

B. Electrochemical Performance

These CV curves provide valuable insights into the charge storage mechanisms, capacitance, and energy storage capabilities of the SC. By subjecting the SC to varying voltage scan rates from 2 mVs^{-1} between 100 mVs^{-1} in potential window 0-1 V, the CV curves were used for the determination of specific capacitance (C_{sp}) of SCs. Figure 3 shows C_{sp} variation with the scan rate in the R-GO based SC. In this study, the CV curve of the R-GO based SC exhibits a remarkable symmetrical and nearly rectangular shape for both electrolyte mediums at low scan rates, indicating exceptional charge storage characteristics, highly reversible electrochemical processes and efficient ion adsorption/desorption kinetics at the electrode-electrolyte interface [35]. The symmetrical nature of the curve signifies minimal energy losses during charge-discharge cycles, highlighting the superior capacitance retention and cycling stability of the R-GO-based SC [36]. The near-rectangular shape at low scan rates underscores the dominance of electric double-layer capacitance, emphasizing the high surface area and conductivity of the R-GO electrodes [37]. The increasing scan rates in R-GO-based SCs prepared with two electrolytes, show changes in the shape, size and symmetry of the CV curves. However, as the scan rate decreases, the CV curves tend to broaden and become more elongated, indicating slower charge-discharge kinetics and reduced ion diffusion rates within the electrode-electrolyte interface. This broadening effect leads to an increase in the size of the CV curves, giving higher charge storage capacities at lower scan rates due to longer charge-discharge time as shown in Fig. 2 [38].

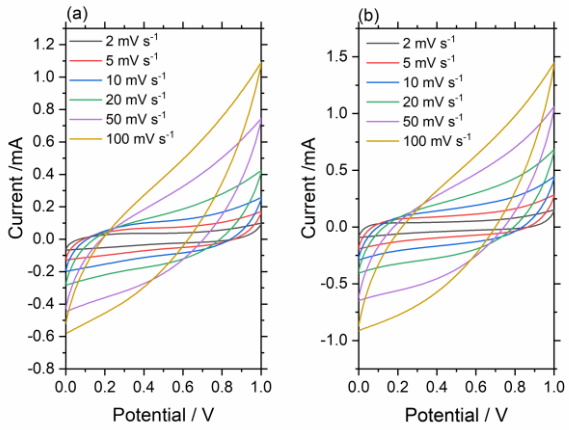

Fig. 2. CVs curves of R-GO based SC with (a) $LiCF_3SO_3$ IL electrolyte (b) 2M H_2SO_4 acidic electrolyte

By using the CV curve in Fig. 2 and integrating the area enclosed by the CV curve, the C_{sp} of the SC was determined using the equation 8. The C_{sp} represents the amount of charge stored per unit mass of the electrode material [39].

$$C_{sp} = 4\frac{\int I\,dt}{V \times S \times M_{ac}} \qquad (8)$$

Where,
I = current
V = voltage range
S = scan rate
M_{ac} = electrochemically active mass of the cell
The term $\int I\,dt$ was calculated by integrating the area enclosed by the CV curves.

TABLE II: C_{SP} VALUES OF R-GO BASED SC WITH TWO ELECTROLYTE MEDIUMS

Scan rate / mV s^{-1}	**Specific capacitance / F g^{-1}**	
	$LiCF_3SO_3$ IL	***2M H_2SO_4***
2	59.04	146.03
5	43.94	118.70
10	33.26	91.99
20	22.66	65.54
50	12.93	37.77
100	7.82	22.75

The observed decrease in C_{sp} of R-GO based SCs when utilizing an IL as compared to an acidic medium can be attributed to several factors. Firstly, the electrolyte significantly influences the interactions between the electrode material and ions, affecting the capacitance [40]. ILs, being composed of large, bulky ions, can exhibit slower ion diffusion kinetics within the porous structure of R-GO electrodes compared to acidic electrolytes with smaller ions. This sluggish ion diffusion may be limited the effective utilization of the high surface area of R-GO, leading to a decrease in C_{sp} [41]. Moreover, the different redox potentials and ion nobilities of ions in ILs versus acidic solutions can have altered the nature of charge storage mechanisms. Additionally, the physicochemical properties of the electrolyte, such as viscosity and conductivity, may have also influenced the ion transport and charge storage processes, contributing to the observed differences in C_{sp} [42].

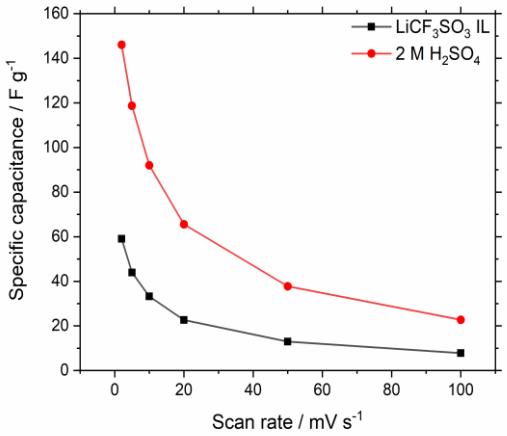

Fig. 3. C_{sp} variation of R-GO based SC with scan rates

GCD curves provide crucial insights into the energy storage mechanisms and capacitive behavior of the SCs. GCD curves taken at various current densities from 0.5 to 5 mA cm^{-2} in this study are shown in Fig. 4. Key parameters such as gravimetric energy density (E_g) and gravimetric power density (P_g) were calculated using GCD curves, which are pivotal for optimizing device design and performance [43].

$$E_g = \frac{CV^2}{2} \qquad (9)$$

$$P_g = \frac{E_g}{\Delta t} \qquad (10)$$

Where:

C_{sp} = specific capacitance of the SC in farads per kilograms.

V = voltage across the SC during charge or discharge in volts

E_g = gravimetric energy density.

P_g = gravimetric power density

Δt = time taken for a complete charge or discharge cycle in seconds.

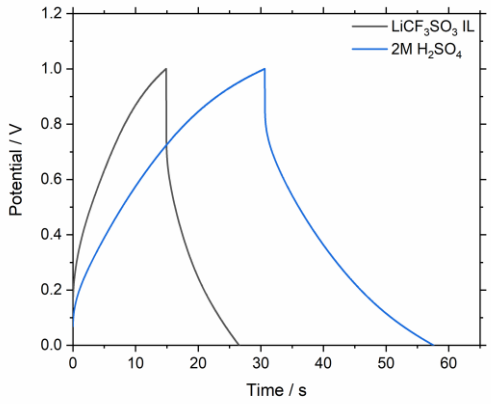

Fig 4. GCD curves of R-GO based SCs at 0.5 mA cm^{-2} current

TABLE III. E_G VALUES AND P_G VALUES OF R-GO BASED SCS WITH TWO ELECTROLYTE MEDIUMS.

Current /mA cm^{-2}	$LiCF_3SO_3$ IL		2M H_2SO_4	
	E_g / Wh kg^{-1}	P_g / kW kg^{-1}	E_g / Wh kg^{-1}	P_g / kW kg^{1}
0.5	2.39	0.74	17.07	2.27
1.0	1.19	7.76	9.94	5.68
2.0	0.28	7.98	5.03	16.33
3.0	0.12	15.29	2.29	33.07
4.0	0.13	15.89	1.12	57.86
5.0	0.11	17.57	0.96	81.55

Fig. 4 shows GCD curves at 0.5 mA cm^{-2} current density for 2M H_2SO_4 acidic electrolyte and $LiCF_3SO_3$ IL electrolyte. Both curves were shown nearly symmetrical behavior. It suggests balanced charge/discharge processes, indicating efficient charge transfer kinetics and ion diffusion within the electrode materials [44]. The gradient of the discharge curve of a SC provides information regarding its internal resistance and charge transfer kinetics. A steep gradient of discharge curve with ionic liquid electrolyte medium and acidic electrolyte medium suggests rapid discharge, indicating efficient charge delivery from the SC [45].

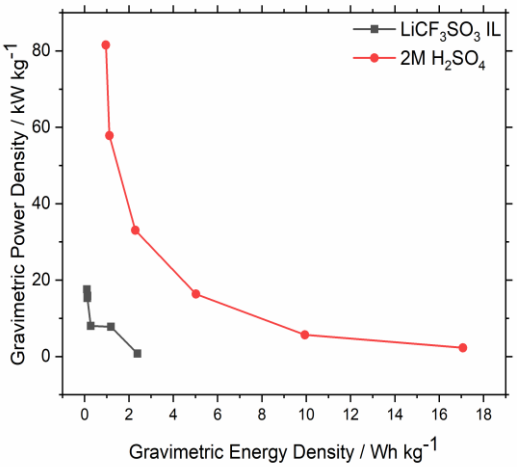

Fig. 5. Variation of E_g vs P_g

In Fig. 5, shows the values of P_g as a function of E_g. The relationship between P_g and E_g is a crucial aspect in assessing the performance of SCs. Typically, there exists a trade-off between these two parameters, where higher E_g often comes at the expense of lower P_g and vice versa. This trade-off arises due to the different mechanisms underlying energy storage and power delivery in SCs [46]. Higher E_g signifies the ability to store more energy per unit mass, whereas higher P_g indicates the capability to deliver energy at a faster rate. Understanding the trade-off relationship between P_g and E_g is essential for optimizing SC designs [47]. SC with H_2SO_4 electrolyte exhibits higher P_g values as shown in Table III, due to their lower ionic resistance, enabling faster charge and discharge rates. However, the energy density of such systems may be relatively lower due to the limited voltage window and lower capacitance associated with acidic electrolytes [48]. The IL electrolyte was given slightly lower power densities compared to acidic electrolytes may be due to higher viscosity and ion diffusion limitations. Therefore, acidic electrolytes are better for applications requiring rapid energy release, such as power buffering and pulse applications [13]. Comparative analysis of E_g and P_g between these two electrolyte systems provides valuable insights into the trade-offs and advantages associated with each, guiding the selection and optimization of electrolytes for tailored SC applications.

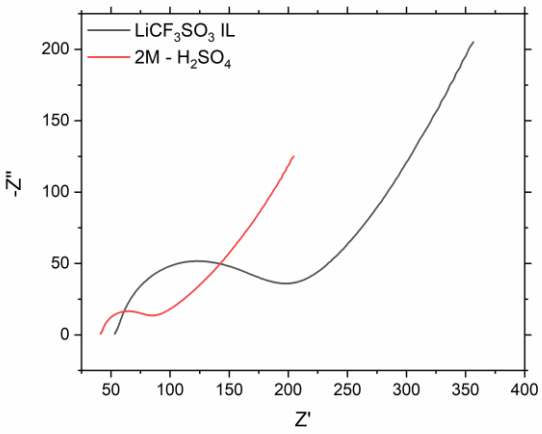

Fig 6. Nyqiust plot of R-GO based SC

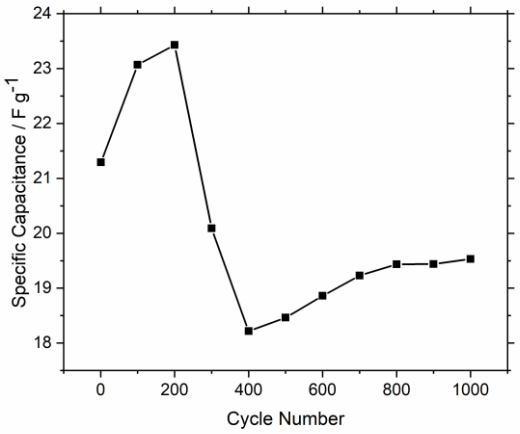

Fig. 7. C_{sp} values as a function of cycle number

Fig. 6 shows Nyqiust plot (NP) of R-GO based SC. The semicircular shape observed at high frequencies represents the charge transfer resistance associated with the interface between the electrode and the electrolyte. The diameter of this semicircle directly correlates with the magnitude of the charge transfer resistance [49]. Additionally, at lower frequencies, the NP often transitions into a linear region, indicative of diffusion-limited processes within the electrode materials. The slope of this linear region reflects the Warburg impedance, representing the diffusion of ions within the electrode pores [50]. A comparative analysis of NP for R-GO based SCs utilizing 2M H_2SO_4 acidic and $LiCF_3SO_3$ IL electrolytes reveals distinct differences in their electrochemical behavior. In SCs with acidic electrolytes, NPs typically exhibit smaller semicircles at high frequencies, indicating lower charge transfer resistance due to the higher conductivity of acidic electrolytes [51]. Conversely, SCs employing IL electrolytes often display larger semicircles, suggesting higher charge transfer resistance attributed to the higher viscosity and slower ion diffusion rates of ILs [12]. Furthermore, the linear regions at lower frequencies in NPs for IL electrolytes may show steeper slopes, indicating enhanced Warburg impedance and potentially higher ion diffusion limitations compared to acidic electrolytes. Overall, comparative analysis of NPs provides valuable insights into the impedance properties and charge transfer kinetics of R-GO-based SCs with different electrolytes, guiding the selection and optimization of electrolytes [40,50].

The cyclic stability of RGO based SC with 2M sulfuric acid electrolyte is determined by sequential CV curves for 1000 cycles at the scan rate 100 mV s^{-1} as shown in Figure 5(b). In the case of SC was charged from 0 V to 1 V. The specific capacitance increases till the 200th and the maximum may be due to heating effects. After 200 cycles, an initial capacitance fades by 22% until 400th cycle as shown in Fig. 7. The observed drop of capacitance after 200 cycles may be due to the presence of unstable oxygen functional groups in RGO or exertion of pseudocapacitance in a slow kinetics course. After 400 cycles, a gradual increment of the specific capacitance was observed until 1000 cycles. The final retention reaches 91.7% after 1000 cycles.

IV. CONCLUSION

In conclusion, the synthesis of R-GO from graphite powder using a modified Hummers method has proven to be an effective approach for fabricating electrode materials for SCs. Through the comparative evaluation of SC performance with $LiCF_3SO_3$ IL and 2M-H_2SO_4 acidic electrolytes, significant insights have been gained. The utilization of acidic electrolyte has demonstrated promising results, showcasing enhanced E_g and C_{sp} due to the improved ion accessibility of the R-GO electrodes. Conversely, while IL electrolyte has shown lower P_g and lower E_g owing to higher ionic resistance and reduced capacitance comparative to the acidic electrolyte. The calculated maximum specific capacitance values of R-GO based SC in 2M H_2SO_4 electrolyte and $LiCF_3SO_3$ ionic liquid electrolyte are 146.03 F g^{-1} and 59.04 F g^{-1} respectively at scan rate 2 mV s^{-1}. R-GO based SC demonstrates highest E_g value 2.39 Wh/kg and 17.07 Wh/kg for $LiCF_3SO_3$ IL electrolyte and 2M – H_2SO_4 acidic electrolyte respectively at 0.5 mA. The R-GO based SC exhibits pronounced stability with 91.7% capacitance retention even after 1000 cycles at a scan rate of 100 mV s^{-1} with 2M – H_2SO_4 acidic electrolyte. These findings underscore the importance of electrolyte selection in tailoring SC performance to specific application requirements. Moreover, the successful synthesis of R-GO and the comprehensive electrochemical characterization presented in this study lay a solid foundation for further research aimed at optimizing SC designs and advancing energy storage technologies for various practical applications.

REFERENCES

[1] W. Raza *et al.*, "Recent advancements in supercapacitor technology," *Nano Energy*, vol. 52, no. June, pp. 441–473, 2018, doi: 10.1016/j.nanoen.2018.08.013.

[2] J. Partridge and D. I. Abouelamaimen, "The role of supercapacitors in regenerative braking systems," *Energies*, vol. 12, no. 14, 2019, doi: 10.3390/en12142683.

[3] J. Yan, Q. Wang, T. Wei, and Z. Fan, "Recent advances in design and fabrication of electrochemical supercapacitors with high energy densities," *Adv. Energy Mater.*, vol. 4, no. 4, 2014, doi: 10.1002/aenm.201300816.

[4] R. Liu *et al.*, "Fundamentals, advances and challenges of transition metal compounds-based supercapacitors," *Chem. Eng. J.*, vol. 412,

no. January, p. 128611, 2021, doi: 10.1016/j.cej.2021.128611.
[5] J. Zhang *et al.*, "The graphene/lanthanum oxide nanocomposites as electrode materials of supercapacitors," *J. Power Sources*, vol. 419, no. December 2018, pp. 99–105, 2019, doi: 10.1016/j.jpowsour.2019.02.059.
[6] P. K. Jha, S. K. Singh, V. Kumar, S. Rana, S. Kurungot, and N. Ballav, "High-Level Supercapacitive Performance of Chemically Reduced Graphene Oxide," *Chem*, vol. 3, no. 5, pp. 846–860, 2017, doi: 10.1016/j.chempr.2017.08.011.
[7] N. Cao and Y. Zhang, "Study of Reduced Graphene Oxide Preparation by Hummers' Method and Related Characterization," *J. Nanomater.*, vol. 2015, 2015, doi: 10.1155/2015/168125.
[8] Y. Hou, S. Lv, L. Liu, and X. Liu, "High-quality preparation of graphene oxide via the Hummers' method: Understanding the roles of the intercalator, oxidant, and graphite particle size," *Ceram. Int.*, vol. 46, no. 2, pp. 2392–2402, 2020, doi: 10.1016/j.ceramint.2019.09.231.
[9] W. Liu and G. Speranza, "Tuning the Oxygen Content of Reduced Graphene Oxide and Effects on Its Properties," *ACS Omega*, vol. 6, no. 9, pp. 6195–6205, 2021, doi: 10.1021/acsomega.0c05578.
[10] W. Ye, H. Wang, J. Ning, Y. Zhong, and Y. Hu, "New types of hybrid electrolytes for supercapacitors," *J. Energy Chem.*, vol. 57, pp. 219–232, 2021, doi: 10.1016/j.jechem.2020.09.016.
[11] J. Zheng, J. A. Lochala, A. Kwok, Z. D. Deng, and J. Xiao, "Research Progress towards Understanding the Unique Interfaces between Concentrated Electrolytes and Electrodes for Energy Storage Applications," *Adv. Sci.*, vol. 4, no. 8, pp. 1–19, 2017, doi: 10.1002/advs.201700032.
[12] S. Pan *et al.*, "Recognition of Ionic Liquids as High-Voltage Electrolytes for Supercapacitors," *Front. Chem.*, vol. 8, no. May, pp. 1–18, 2020, doi: 10.3389/fchem.2020.00261.
[13] H. Liu and H. Yu, "Ionic liquids for electrochemical energy storage devices applications," *J. Mater. Sci. Technol.*, vol. 35, no. 4, pp. 674–686, 2019, doi: 10.1016/j.jmst.2018.10.007.
[14] C. Xu, "Thermal Stability of Ionic Liquids : Current Status and," 2021.
[15] J. Yan, S. Li, B. Lan, Y. Wu, and P. S. Lee, "Rational Design of Nanostructured Electrode Materials toward Multifunctional Supercapacitors," *Adv. Funct. Mater.*, vol. 30, no. 2, pp. 1–35, 2020, doi: 10.1002/adfm.201902564.
[16] M. Engineering, C. S. Division, and K. Wordsx-ray, "STRUCTURAL TRANSFORMATIONS INDUCED IN GRAPHITE BY GRINDING : ANALYSIS OF 002 X-RAY DIFFRACTION LINE PROFILES," vol. 2, no. 6, 1990.
[17] A. Kaushal, S. K. Dhawan, and V. Singh, "Determination of crystallite size, number of graphene layers and defect density of graphene oxide (GO) and reduced graphene oxide (RGO)," *AIP Conf. Proc.*, vol. 2115, no. July, pp. 1–5, 2019, doi: 10.1063/1.5112945.
[18] L. Stobinski *et al.*, "Graphene oxide and reduced graphene oxide studied by the XRD, TEM and electron spectroscopy methods," *J. Electron Spectros. Relat. Phenomena*, vol. 195, pp. 145–154, 2014, doi: 10.1016/j.elspec.2014.07.003.
[19] Q. A. Khan, A. Shaur, T. A. Khan, Y. F. Joya, and M. S. Awan, "Characterization of reduced graphene oxide produced through a modified Hoffman method," *Cogent Chem.*, vol. 3, no. 1, p. 1298980, 2017, doi: 10.1080/23312009.2017.1298980.
[20] H. H. Huang, K. K. H. De Silva, G. R. A. Kumara, and M. Yoshimura, "Structural Evolution of Hydrothermally Derived Reduced Graphene Oxide," *Sci. Rep.*, vol. 8, no. 1, pp. 2–10, 2018, doi: 10.1038/s41598-018-25194-1.
[21] B. Lesiak *et al.*, "Chemical and structural properties of reduced graphene oxide—dependence on the reducing agent," *J. Mater. Sci.*, vol. 56, no. 5, pp. 3738–3754, 2021, doi: 10.1007/s10853-020-05461-1.
[22] J. C. Silva Filho, E. C. Venancio, S. C. Silva, H. Takiishi, L. G. Martinez, and R. A. Antunes, "A thermal method for obtention of 2 to 3 reduced graphene oxide layers from graphene oxide," *SN Appl. Sci.*, vol. 2, no. 8, pp. 1–8, 2020, doi: 10.1007/s42452-020-03241-9.
[23] C. Series, "An investigation of the Structural , Electrical and Optical Properties of Graphene-Oxide Thin Films Using Different Solvents An investigation of the Structural , Electrical and Optical Properties of Graphene-Oxide Thin Films Using Different Solvents," 2021, doi: 10.1088/1742-6596/1795/1/012052.
[24] N. I. Zaaba, K. L. Foo, U. Hashim, S. J. Tan, W. W. Liu, and C. H. Voon, "Synthesis of Graphene Oxide using Modified Hummers Method: Solvent Influence," *Procedia Eng.*, vol. 184, pp. 469–477, 2017, doi: 10.1016/j.proeng.2017.04.118.
[25] S. Farah, A. Farkas, J. Madarász, and K. László, "Comparison of thermally and chemically reduced graphene oxides by thermal analysis and Raman spectroscopy," *J. Therm. Anal. Calorim.*, no. 0123456789, 2020, doi: 10.1007/s10973-020-09719-3.
[26] A. Y. Lee *et al.*, "Raman study of D* band in graphene oxide and its correlation with reduction," *Appl. Surf. Sci.*, vol. 536, no. September 2020, p. 147990, 2021, doi: 10.1016/j.apsusc.2020.147990.
[27] A. J. Pollard *et al.*, "Quantitative characterization of defect size in graphene using Raman spectroscopy," *Appl. Phys. Lett.*, vol. 105, no. 25, 2014, doi: 10.1063/1.4905128.
[28] K. K. H. De Silva, P. Viswanath, V. K. Rao, S. Suzuki, and M. Yoshimura, "New Insight into the Characterization of Graphene Oxide and Reduced Graphene Oxide Monolayer Flakes on Si-Based Substrates by Optical Microscopy and Raman Spectroscopy," *J. Phys. Chem. C*, vol. 125, no. 14, pp. 7791–7798, 2021, doi: 10.1021/acs.jpcc.1c01152.
[29] K. K. H. De Silva, H. H. Huang, R. Joshi, and M. Yoshimura, "Restoration of the graphitic structure by defect repair during the thermal reduction of graphene oxide," *Carbon N. Y.*, vol. 166, pp. 74–90, 2020, doi: 10.1016/j.carbon.2020.05.015.
[30] S. Eigler, C. Dotzer, and A. Hirsch, "Visualization of defect densities in reduced graphene oxide," *Carbon N. Y.*, vol. 50, no. 10, pp. 3666–3673, 2012, doi: 10.1016/j.carbon.2012.03.039.
[31] P. Puech *et al.*, "Analyzing the Raman Spectra of Graphenic Carbon Materials from Kerogens to Nanotubes: What Type of Information Can Be Extracted from Defect Bands?," *C*, vol. 5, no. 4, p. 69, 2019, doi: 10.3390/c5040069.
[32] Y. Wang *et al.*, "Reduced graphene oxide film with record-high conductivity and mobility," *Mater. Today*, vol. 21, no. 2, pp. 186–192, 2018, doi: 10.1016/j.mattod.2017.10.008.
[33] Y. Hu, S. Song, and A. Lopez-valdivieso, "Effects of Oxidation on the Defect of Reduced Graphene Oxides in Graphene Preparation School of Resources and Environmental Engineering , Wuhan University of Instituto de Metalurgia , Universidad Autonoma de San Luis Potosi , Av . Sierra Leona," *J. Colloid Interface Sci.*, 2015, doi: 10.1016/j.jcis.2015.02.059.
[34] A. Wróblewska *et al.*, "Statistical analysis of the reduction process of graphene oxide probed by Raman spectroscopy mapping," *J. Phys. Condens. Matter*, vol. 29, no. 47, 2017, doi: 10.1088/1361-648X/aa92fe.
[35] C. Ogata *et al.*, "All-Graphene Oxide Flexible Solid-State Supercapacitors with Enhanced Electrochemical Performance," *ACS Appl. Mater. Interfaces*, vol. 9, no. 31, pp. 26151–26160, 2017, doi: 10.1021/acsami.7b04180.
[36] T. Uddin, A. Sarker, S. M. S. Mahmud, and B. Shuchi, "Performance enhancement of graphene / GO / rGO based supercapacitors : A comparative review," *Mater. Today Commun.*, vol. 28, no. April, p. 102685, 2021, doi: 10.1016/j.mtcomm.2021.102685.
[37] H. Youn, S. Bak, M. Kim, and C. Jaye, "High-Surface-Area Nitrogen-Doped Reduced Graphene Oxide for Electric Double-Layer Capacitors," pp. 1875–1884, 2015, doi: 10.1002/cssc.201500122.
[38] Y. Gong, D. Li, Q. Fu, and C. Pan, "Influence of graphene microstructures on electrochemical performance for supercapacitors," *Prog. Nat. Sci. Mater. Int.*, vol. 25, no. 5, pp. 379–385, 2015, doi: 10.1016/j.pnsc.2015.10.004.
[39] O. Gharbi, M. T. T. Tran, B. Tribollet, M. Turmine, and V. Vivier, "Revisiting cyclic voltammetry and electrochemical impedance spectroscopy analysis for capacitance measurements," *Electrochim. Acta*, vol. 343, p. 136109, 2020, doi: 10.1016/j.electacta.2020.136109.
[40] Y. Chen and Y. Ma, "High performance supercapacitors based on reduced graphene oxide in aqueous and ionic liquid electrolytes," *Carbon N. Y.*, vol. 49, no. 2, pp. 573–580, 2010, doi: 10.1016/j.carbon.2010.09.060.
[41] J. Kim and S. Kim, "Ac ce p te us cr t," *Appl. Surf. Sci.*, no. 2014, 2013, doi: 10.1016/j.apsusc.2013.12.156.
[42] R. Yan, M. Antonietti, and M. Oschatz, "Toward the Experimental Understanding of the Energy Storage Mechanism and Ion Dynamics in Ionic Liquid Based Supercapacitors," vol. 1800026, pp. 1–12, 2018, doi: 10.1002/aenm.201800026.
[43] A. Laheäär, P. Przygocki, Q. Abbas, and F. Béguin, "Electrochemistry Communications Appropriate methods for

evaluating the ef fi ciency and capacitive behavior of different types of supercapacitors," *Electrochem. commun.*, vol. 60, pp. 21–25, 2015, doi: 10.1016/j.elecom.2015.07.022.

[44] K. Liu, Z. Wang, L. Shi, S. Jungsuttiwong, and S. Yuan, "Ionic liquids for high performance lithium metal batteries," *J. Energy Chem.*, 2020, doi: 10.1016/j.jechem.2020.11.017.

[45] R. Thangavel, A. G. Kannan, R. Ponraj, V. Thangavel, D. W. Kim, and Y. S. Lee, "High-energy green supercapacitor driven by ionic liquid electrolytes as an ultra-high stable next-generation energy storage device," *J. Power Sources*, vol. 383, no. January, pp. 102–109, 2018, doi: 10.1016/j.jpowsour.2018.02.037.

[46] J. Zhao and A. F. Burke, "Electrochemical Capacitors : Performance Metrics and Evaluation by Testing and Analysis," vol. 2002192, pp. 1–29, 2020, doi: 10.1002/aenm.202002192.

[47] J. Zhang and X. S. Zhao, "On the Configuration of Supercapacitors for Maximizing Electrochemical Performance," pp. 818–841, 2012, doi: 10.1002/cssc.201100571.

[48] W. Qin *et al.*, "Mini-Review on the Redox Additives in Aqueous Electrolyte for High Performance Supercapacitors," 2020, doi: 10.1021/acsomega.9b04063.

[49] P. Xu *et al.*, "A high surface area N-doped holey graphene aerogel with low charge transfer resistance as high performance electrode of non- fl ammable thermostable supercapacitors," vol. 149, pp. 452–461, 2019, doi: 10.1016/j.carbon.2019.04.070.

[50] J. Huang, "Diffusion impedance of electroactive materials, electrolytic solutions and porous electrodes: Warburg impedance and beyond," *Electrochim. Acta*, vol. 281, pp. 170–188, 2018, doi: 10.1016/j.electacta.2018.05.136.

[51] B. A. Mei, O. Munteshari, J. Lau, B. Dunn, and L. Pilon, "Physical Interpretations of Nyquist Plots for EDLC Electrodes and Devices," *J. Phys. Chem. C*, vol. 122, no. 1, pp. 194–206, 2018, doi: 10.1021/acs.jpcc.7b10582.

LED to LED Multiple Input Single Output (MISO) Visible Light Communication (VLC) System

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***Abstract*— This project had investigated the development and performance of a Multiple-Input Single-Output (MISO) Visible Light Communication (VLC) system using LED-to-LED technology to facilitate unidirectional communication from multiple users to a single user. The transmitter side of the system had comprised two power LEDs, while the receiver side had featured a single power LED. The decision to employ a MISO system had been made due to its capability to achieve higher data rates and maintain good communication quality, even in the presence of interference and noise, compared to a conventional VLC system utilizing Single Input Single Output (SISO) architecture.**

The system had utilized two ESP32 WROOM microcontroller boards, programmed with Python, employing On-Off Keying (OOK) modulation to facilitate data transmission. The transmitter setup had included a 10W COB blue power LED and a 30W COB blue power LED, driven by 2N222 and D400 transistors, and managed by a 270-ohm resistor. On the receiver side, a 1W COB blue power LED had been used in conjunction with an LM358 operational amplifier (OPAMP) and a 1 Megaohm resistor to recover the transmitted signals.

The results had indicated that the MISO LED-to-LED communication system had achieved significantly higher data rates and better communication quality than SISO systems, making it a promising approach for future wireless communication technologies. This research had contributed to the advancement of VLC systems by providing a detailed analysis of MISO configurations and their potential to overcome the limitations of traditional SISO architectures.

***Index Terms*—COB LEDs, Data rates, ESP32 WROOM, Interference and noise, LED-to-LED technology, Multiple-Input Single-Output (MISO),On-Off Keying (OOK),Operational Amplifier (LM358), Power LEDs, Single Input Single Output (SISO),Transistor circuits (2N222, D400),Unidirectional communication, Visible Light Communication (VLC).**

I. INTRODUCTION

This project had undertaken an in-depth exploration of a Multiple-Input Single-Output (MISO) Visible Light Communication (VLC) system utilizing LED-to-LED technology. VLC, a cutting-edge optical wireless communication method, had leveraged the visible light spectrum for transmitting data, distinguishing itself with several advantages over conventional radio frequency systems. This technology had proved particularly advantageous in indoor environments, where it had delivered reliable, high-bandwidth communication without competing with existing radio frequencies. Additionally, VLC's inherent characteristics, such as its ability to utilize ambient light sources and its minimal health concerns due to non-ionizing radiation, had underscored its relevance and potential.

The focus had been on addressing the limitations inherent in Single Input Single Output (SISO) VLC systems. SISO systems, while foundational in VLC technology, had been constrained by their lower data rates and limited communication efficiency. By adopting a MISO architecture, which employed multiple LEDs as transmitters and a single LED as a receiver, the research had aimed to significantly enhance both data throughput and communication quality.

Advantages of MISO over SISO Systems:

• **Enhanced Data Rate:** MISO systems had been designed to transmit data from multiple sources to a single destination, thereby facilitating higher data rates compared to SISO systems.

• **Improved Communication Quality:** The integration of multiple LEDs for transmission had resulted in better signal strength and greater robustness against interference.

• **Optimized Resource Utilization:** MISO configurations had effectively distributed the data load across multiple LEDs, optimizing the overall performance of the communication system.

Advantages of LEDs as Transmitters and Receivers:

• **Economic Efficiency:** LEDs had been a cost-effective alternative to traditional lighting and photodetection technologies.

• **Versatility:** The ability of LEDs to function as both light emitters and receivers had enabled bidirectional communication with fewer components.

• **Resistance to Interference:** LEDs had demonstrated superior robustness against sunlight interference compared to other photodetectors.

• **Longevity and Reliability:** With their extended operational life and reliability, LEDs had been well suited for long-term use in communication systems.

• **Narrow Wavelength Sensitivity:** LEDs used as receivers had exhibited sensitivity to a narrow band of wavelengths, which had reduced the need for costly optical filters.

Fig.01 : LED to LED MISO System

The research had also involved the use of two ESP32 WROOM microcontroller boards, programmed with Python and employing On-Off Keying (OOK) modulation for data transmission. This approach had demonstrated the practical feasibility and effectiveness of the proposed system. Through detailed experimentation and analysis, this had highlighted how leveraging the unique properties of LEDs and employing a MISO architecture had led to significant improvements in data rates and communication reliability.

A. Motivation

This research had demonstrated the effectiveness of the MISO VLC system through a series of experiments designed to measure data rates and Bit Error Rate (BER) across various distances. Additionally, the study had evaluated the system's performance under different conditions, including the use of power LEDs of different colors as input signals. The decision to employ a MISO architecture had been driven by its capability to achieve higher data rates and maintain robust communication quality, even under varying environmental conditions.

This had illustrated the potential of MISO VLC systems to surpass traditional SISO configurations, presenting a robust and high-speed communication solution with numerous applications in indoor environments. This work had made a valuable contribution to the field of VLC by providing a comprehensive evaluation of MISO system configurations and their advantages over conventional SISO architectures.

B. Related work in Literature

A lot of projects employing VLC systems have been reported and the most common receiver has been a Photodiode. This project has aimed to gather information with the aid of more LEDs. Most of the works had used OOK and PWM modulations to achieve 10 Mbps data rates. The colors of LEDs used had varied by project. Red LEDs have been deployed in both the transmitter and the receiver sections to facilitate seamless higher data rate transmissions [1]. Data rate could be achieved well looking at the distance between the transmitter and receiver. For data transmission and multi-level dimming in unidirectional VLC system, PWM along with OOK was explored. Edge detection and static threshold detection were the two of the earliest steps during the two-step decoding of OOK signal at LED receiver during its OFF periods. This kind of communication device, however, was limited by certain factors like device portability (when one of the LED devices was moved) and ambient light changes brought about by natural light (day night changes) [2]. In such a visible light communication system, the transmitter had been one of the most important components, where data was transferred using LEDs. In this case several colored LEDs had been used. LEDs had been the best choice for a VLC light source as they were energy efficient and emitted white light in addition to the applicable [wavelength] conversion methods. The best way to create white light had been with the use of trichromatic (red, green and blue) colored light or RGB. This technique however had been beneficial because it could create huge bandwidth allowing the high transmission rate. And yet, it has been rather difficult to modulate them because of their intricate nature [2].

The K-means clustering method had been applied to the light measurements collected in the data frame. This made use of the predicted duty cycle of the emitted PWM signal to estimate a level which was later used for bit decoding. The details of the receiver design in an operative prototype LED system and the evidence extending the VLC range included some of the previous studies [3].

Transmitter	Receiver	Distance	Data Rate	Modulation
Red LED	Red LED	15 cm	1 kbps	OOK
Red LED	Photo-diode	6 m	150 Mbps	-
White LED	Photo-diode	1.65 m	200 Mbps	OOK
Monochromatic LED	Monochromatic LED	20 cm	10 Mbits/s	OOK
LED (CREE CXA2520)	Photo-diode Photo-diode(OPT101)	1.3 m	1.6 kbps	OPPM
ViReader (LED+Photo-diode)	ViTag (Photo-diode+LCD)	2.4 m	10 kbps	OOK

Table 01 : Summary of researches done early

Other techniques used for producing white light included dichromatic-mostly blue and yellow-and tetrachromatic-blue, cyan, green, and red. In these light bulbs, the driver regulated the current flowing through the LEDs, thereby directly affecting the brightness of the illumination [4]. Transistors, which had regulated the current flowing to the LED, had controlled the high-frequency light signals emitted by the LED and, therefore, made the communication invisible by the human eye. The LED and driving circuitry had been the main components of the transmitter. Drivers based on MOSFET, microcontroller, and FPGA technology had been used [5].

Usually, VLC transceivers have been made up of optical filters, optical concentrators and amplification circuits. Photodiodes used to be the most common receivers to detect and capture the incoming signals and then turn them into photocurrents [2]. Silicon photodiodes, PIN diodes and avalanche photodiodes were used in VLC systems while few experimental studies in most cases on receivers using LEDs have been done. Normally, LEDs have been used as light emitters where they can also be photo-sensors. In this case, their sensitivity has been limited to the same or shorter wavelengths compared to the main wavelength they emit. At the same time an LED used as a detector could have been sensitive to wavelengths equal or less than its primary wavelength. This characteristic of LEDs provided a possibility to fabricate an inexpensive gadget demonstrating the photoelectric effect [3]. Recently, people started to become curious about using systems that combined

broadcasting and receiving in modulated LED light output. Several areas had been examined including networked lighting controls, consumer infotainment low data rate applications, and lighting as a means of communication. This method's benefit was that besides lighting, LEDs could also serve as sensors and VLC [5]. The first two stages of the two-way decoding method used at the LED receiver for decoding the OOK signal during OFF periods included edge detection as well as static threshold detection. However, VLC range of such a system had been limited because of issues like changing intensities of surrounding light (due to daylight variations) and whether the gadget could be transported (for instance if one among led devices was moved). This series of work used blue, green and red LEDs for a set of experiments to demonstrate the use wavelength (color) in optical wireless communications. Measurements have been made with various pairs of LED links acting both as transmitters and receivers. Each of sending and receiving green, yellow, red wavelengths were used to examine depending results from other side also measured output signal strength (looking through Moraima) that sometimes we will use more longer wavelength LEDs detecting shorter wave length LEDs. After an optimal link was found, measured signal results were analyzed to determine performance and the relationship between intensity and distance. The best-performing links were Blue-Blue, White-Green, White-Yellow, Green-Yellow, Red-Red, Green-Red, Yellow-Yellow, and Yellow-Red [6].

II. METHODOLOGY

A. Overall Methodology

The transmitter has been constructed utilizing a 10W COB blue power LED, a 30W COB blue power LED, 2N222 power transistor, D400 transistor, ESP32 WROOM board, and a 270-ohm resistor. For the receiver, a circuit was designed comprising a 1W COB blue power LED, an LM358 operational amplifier (OPAMP), a 1 Megaohm resistor, and an ESP32 WROOM board. The components had been carefully selected to ensure optimal performance for visible light communication (VLC), with particular attention to achieving the necessary data rates and maintaining stable power levels. The ESP32 WROOM boards had been programmed in Python to efficiently manage data transmission and reception. On-Off Keying (OOK) modulation had been implemented at the transmitter, allowing the data to be encoded onto the light emitted by the LEDs. The ESP32 board on the receiver side had been coded to accurately decode the incoming light signals back into data. Initial testing had been carried out on both the SISO (Single Input Single Output) and MISO (Multiple Input Single Output) systems to verify their basic functionality.

Calibration processes had been conducted to ensure that the LEDs were correctly transmitting and receiving data and that the communication link was stable and reliable. The data rates for both SISO and MISO configurations were measured under controlled conditions. These measurements had been taken at various distances between the transmitter and receiver to evaluate the system's performance across different ranges. Additionally, the Bit Error Rate (BER) had been measured for both SISO and MISO systems at varying distances. An analysis had been performed to understand how the BER changed with distance, aiming to establish the relationship between distance and communication reliability. A comparative study had been undertaken between the SISO and MISO systems, focusing on data rates and BER. The study had highlighted the improvements in data rate and communication reliability achieved by the MISO system compared to the SISO system. Furthermore, the efficiency of the MISO system had been discussed in terms of its ability to enhance data rates and its applicability to practical VLC scenarios. Differences in performance between the 10W and 30W LEDs within the MISO system had been assessed to determine the optimal configuration. Underscoring the success of the MISO system in attaining higher data rates and improved communication reliability.

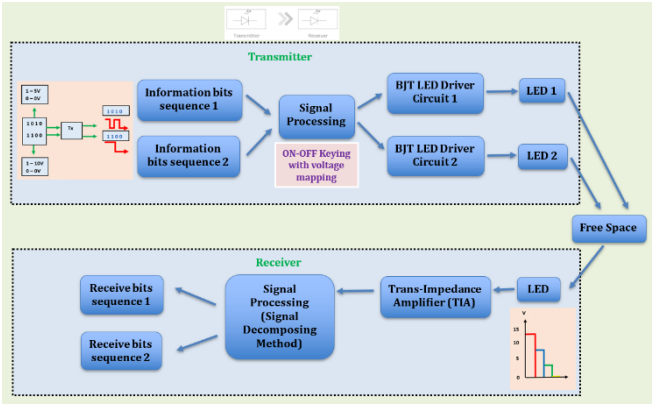

Fig. 02 : Block Diagram

B. Simulation Based Study

I. Transmitter Side

The transmitter circuit diagram is presented here, created using Proteus.

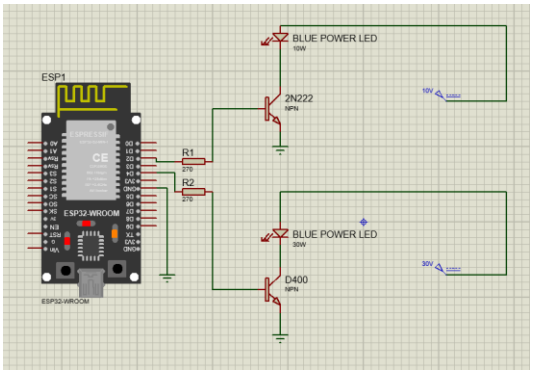

Fig .03 : Tx Proteus Simulation

This figure illustrates how the transmitter side operates.

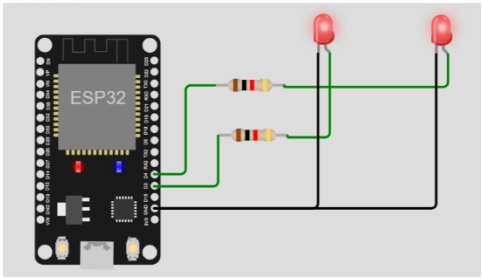

Fig .04: Transmitter Side

II. Receiver Side

The receiver side circuit diagram is presented here, created using Proteus

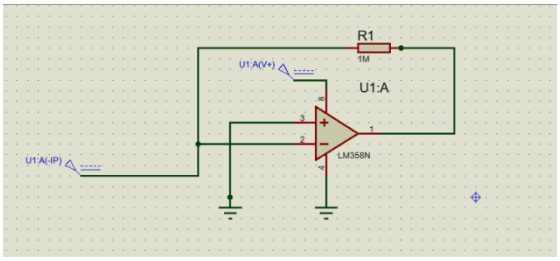

Fig .05 : Rx Proteus Simulation

C. Hardware Implementation

Components and their functionalities

a. Transmitter Side

I. 10W COB Blue Power LED

Selected for its high luminous intensity, which ensures long-distance signal transmission with minimal strength loss

Fig 06 : 10W COB Blue Power LED

II. 30W COB Blue Power LED

Chosen for its higher power output, enhancing total light output and improving signal strength over greater distances.

Fig .07 : 30W COB Blue Power LED

III. 2N222 power transistor

Used to amplify current to the LEDs, selected for its high switching speed and ability to handle high-current loads efficiently.

Fig .08 : 2N222

IV. D400 Transistor

Included for current amplification and rapid switching, selected for its high gain and low saturation voltage, ideal for OOK modulation.

Fig .09 :D400

V. ESP32 WROOM Board

Chosen for its dual-core processor and real-time processing capabilities, essential for efficient data encoding and transmission control.

Fig .10: ESP32

VI. 270 ohm Resistor

Used to limit current, selected to protect the LEDs by ensuring safe operation and preventing overheating.

Fig. 11 : 270 ohm

b. Receiver Side

I. 1W COB Blue Power LED

Chosen for its high sensitivity to light, ensuring effective signal detection and conversion to electrical signals.

Fig. 12: 1W COB Blue LED

II. LM358 Operational Amplifier (Op-Amp)

Selected for its low power consumption and ability to amplify weak signals, making them strong enough for processing.

Fig. 13 : LM358

III. 1 Megaohm Resistor

Used to set the Op-Amp gain, chosen for its high resistance to control amplification and maintain signal integrity.

Fig. 14: 1 ohm

D. Hardware Setup

Basic Hardware Setup :

The basic hardware setup of our project is shown here.

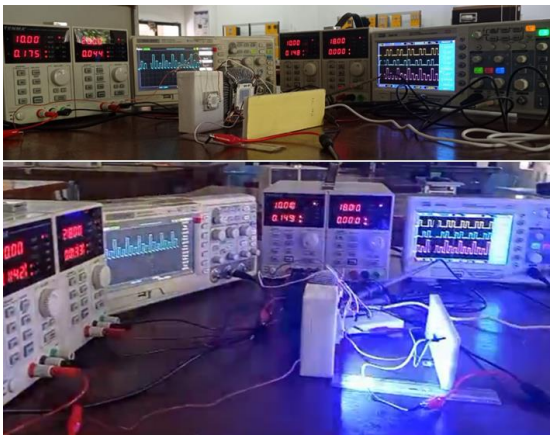

Fig. 15 : Basic Hardware Setup

E. Experimental Measurements and Analysis

Transmitted Signal and Received signal:

Based on the basic hardware setup, the combination of transmitted signals is received as depicted.

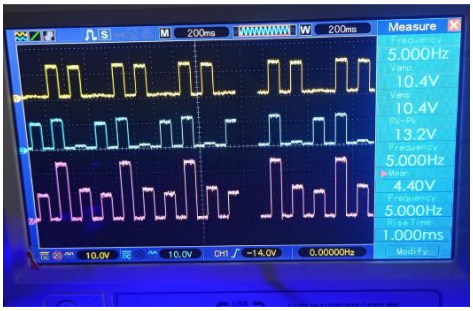

Fig. 16: Transmitted Signal

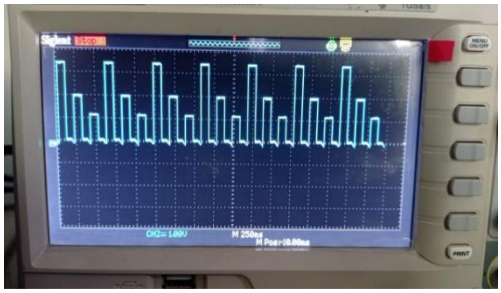

Fig. 17 : Received Signal

F. Normal LED VS Power LED :

The results comparing the received signal power of Power LEDs versus standard LEDs are shown here.

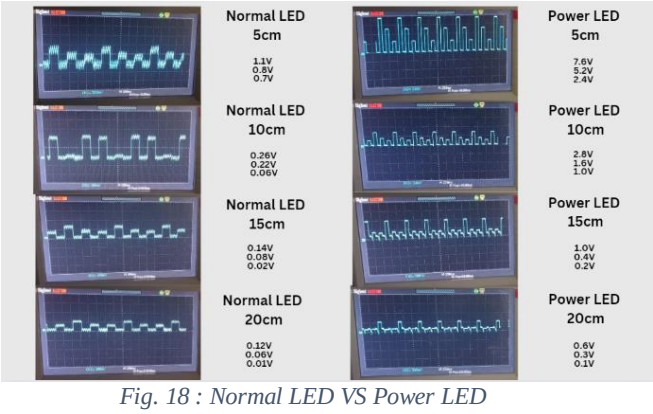

Fig. 18 : Normal LED VS Power LED

H. Received Signal Voltage Vs Distance :

Here is a depiction of the received signal voltage in relation to distance.

Distance (cm)	State	Normal LED (V)	Power LED (V)
5	10	0.7	2.4
	01	0.8	5.2
	11	1.1	7.6
10	10	0.06	1.0
	01	0.22	1.6
	11	0.26	2.8
15	10	0.02	0.2
	01	0.08	0.4
	11	0.14	1.0
20	10	0.01	0.1
	01	0.06	0.3
	11	0.12	0.6

Table 02 : Received Signal Voltage VS Distance

State	10W	30W
10	On	Off
01	Off	On
11	On	On
00	off	off

G. Received Signal Voltage Vs Distance Graph:

This graph illustrates the relationship between received signal voltage and distance :

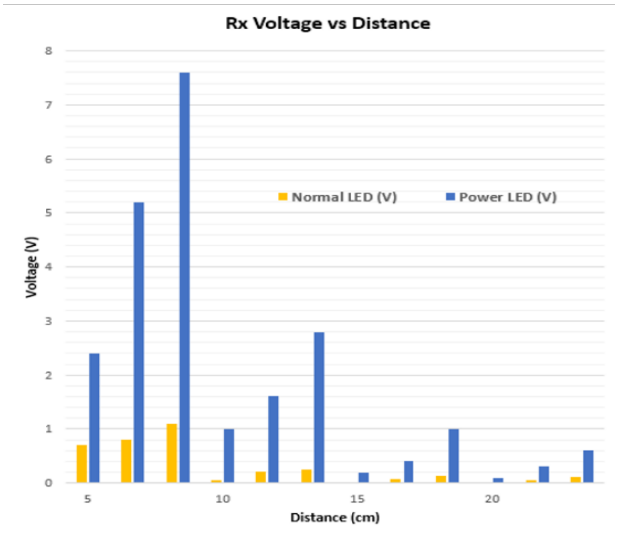

Fig. 19 : Received Signal Voltage VS Distance

Full Hardware Setup :

Following the enhancements, the complete hardware setup of our project is presented here.

Fig. 20 : Full Hardware Setup

a. Transmitter Side

On the transmitter side of the full hardware setup that had been designed, PIN 2 had been configured for the 10W blue power LED with a 2N222 transistor base, and PIN 4 had been configured for the 30W blue power LED with a D400 transistor base. The 10W power LED had been supplied with 10V and 800mA, while the 30W power LED had received 30V and 800mA. Initially, it had been aimed to demonstrate that the transmitted signals could be successfully combined from the receiver side. Using the basic setup, this had been achieved with both power LEDs and regular LEDs.

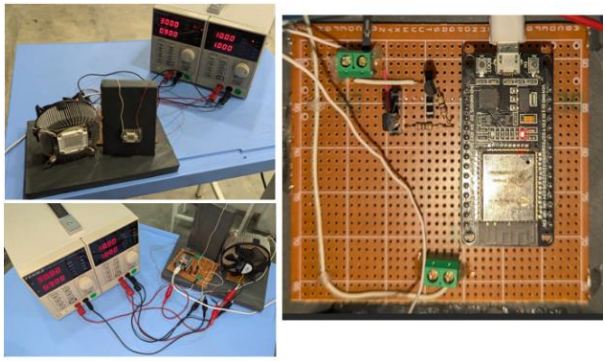

Fig. 21 : Transmitter Side

It had then been aimed to improve the setup by ensuring that the transmitter-side bit stream matched the receiver-side

output for different bit streams (16, 64, 256), across varying distances (10 cm, 15 cm, 20 cm, 25 cm, 30 cm, 35 cm, 40 cm, 45 cm, 50 cm), and at both low and high data rates (10 bps, 20 bps, 80 bps) for MISO and SISO systems. The results are presented in the following sections. The ESP32 microcontroller had been selected with the Thonny IDE, and code tailored to the setup had been written. After the bit stream had been transmitted based on specific calculations, a Real-Time Clock (RTC) had been used for optimal synchronization. Following these calculations, an error-free output bit stream had been obtained.

For further improvements, the setup had been redesigned with different color power LEDs, and 10W and 30W white power LEDs had been used on the transmitter side to obtain additional measurements.

b. Receiver Side

In this MISO system, a 1W blue power LED had been employed, and according to the basic hardware setup, the two transmitter signals had been successfully combined at the receiver side. After improvements had been made, the 1W LED had been aligned with the two transmitter bulbs. As the system had been running using On-Off Keying (OOK) modulation, the transmitted signals had been detected by the receiver, which had begun calculating the threshold values. Based on these values, the system had correctly identified the bit stream from the receiver side. Various factors, such as distance, light interference, or noise, could have caused variations in the results.

When light is detected by the LED, the current through the 1.2 megaohm resistor increases, resulting in a higher voltage drop across the resistor. Conversely, in the absence of light, the voltage drop across the resistor decreases. The voltage across the resistor is then input into a comparator to ensure a stable HIGH or LOW state, depending on whether the LED is ON or OFF. The LED is utilized to convert the received light signal into an electrical signal. This electrical signal is processed by a transimpedance amplifier circuit. To stabilize the circuit, a sufficiently large capacitor must be placed in parallel with the feedback resistor. This type of electronic configuration is typically implemented using an operational amplifier circuit.

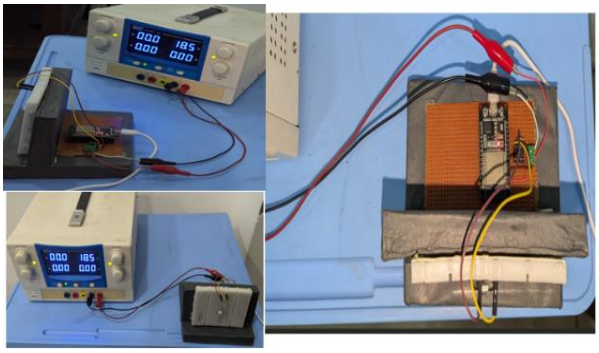

Fig. 22 : Receiver Side

For further improvements, 1W white, red, and green LEDs had been used on the receiver side with white power LEDs on the transmitter side to conduct measurements and color comparisons.

III. EXPERIMENTED RESULTS

i. Comparison of BER Vs. Distance for MISO SYSTEM

A. Data Rates and No of Bits (16 bits , 256 bits)

Fig. 23: Data rate of 10 bits/s had revealed a significant increase in BER with distance, particularly beyond 25 cm. For 16-bit data, the BER had shown a 10% rise from 25 cm to 35 cm and a steeper 36.25% increase from 35 cm to 50 cm. In the case of 256-bit data, the BER gradient had been approximately 15.71% between 25 cm and 35 cm, and 19.92% from 35 cm to 50 cm.

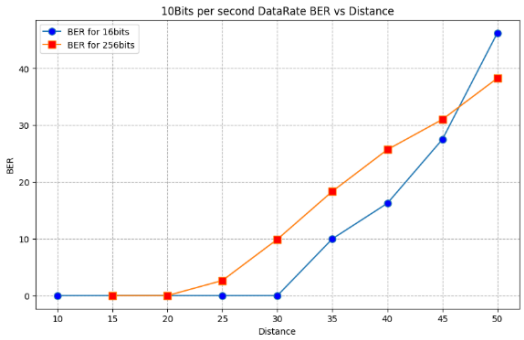

Fig. 23 : 10bps

Fig. 24: 20 bits/s data rate had shown a significant increase in BER as distance increased, particularly beyond 25 cm. For 16-bit data, the BER had risen by 6.25% between 25 cm and 35 cm and by 20% from 35 cm to 50 cm. For 256-bit data, the BER had increased by 13.59% between 25 cm and 35 cm and by 27.11% from 35 cm to 50 cm.

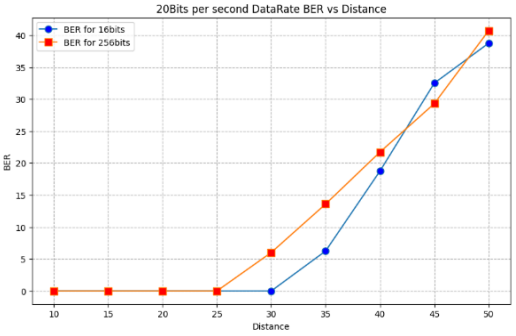

Fig. 24 : 20bps

B. No of Bits and Data Rates (10 bits/s , 20 bits/s)

Fig. 25: Data rates of 10 bits/s and 20 bits/s for 16-bit data had shown a significant increase in BER with distance, particularly after 25 cm. At 10 bits/s, the BER had risen by

10% between 25 cm and 35 cm and by 36.25% from 35 cm to 50 cm. For the 20 bits/s rate, the BER had increased by 6.25% from 25 cm to 35 cm and by 32.5% from 35 cm to 50 cm.

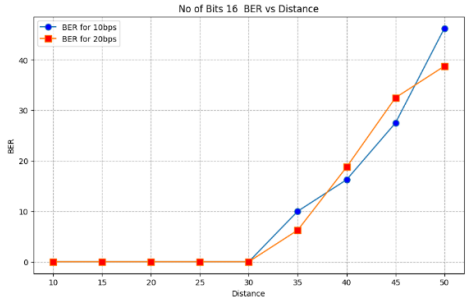

Fig. 25 : 16 bits

Fig. 26: Data rates of 10 bits/s and 20 bits/s for 256-bit data had shown a steady increase in BER as distance increased, particularly after 25 cm. At 10 bits/s, the BER had risen by 15.71% between 25 cm and 35 cm and by 19.92% from 35 cm to 50 cm. For the 20 bits/s rate, the BER had increased by 7.57% from 25 cm to 35 cm and by 27.11% from 35 cm to 50 cm.

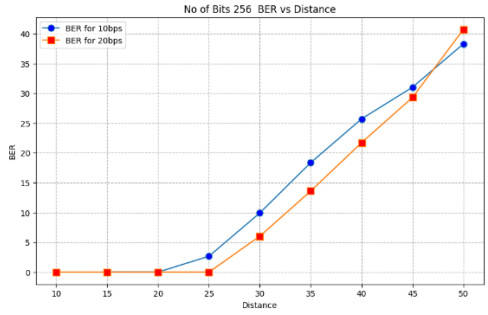

Fig. 26 : 256 bits

ii. Comparison of BER Vs. Distance for SISO SYSTEM

A. Data Rates and No of Bits (16 bits , 256 bits)

Fig. 27: SISO system at a data rate of 10 bits/s had revealed a significant increase in BER with distance. For 16-bit data, the BER had escalated from 0% to 42.5% between 35 cm and 50 cm, resulting in a gradient of 42.5%. For 256-bit data, the BER had risen from 2.65% to 31.48% over the same distance, reflecting a gradient of 28.83%.

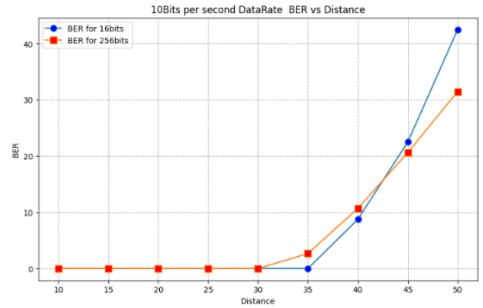

Fig. 27: SISO 10bps

Fig. 28: SISO system at a 20 bits/s data rate had demonstrated a substantial increase in BER with distance. For 16-bit data, the BER had increased by 8.75% from 25 cm to 35 cm and by 27.5% from 35 cm to 50 cm. For 256-bit data, the BER had risen by 7.88% between 25 cm and 35 cm and by 28.35% from 35 cm to 50 cm.

B. No of Bits and Data Rates (10 bits/s , 20 bits/s)

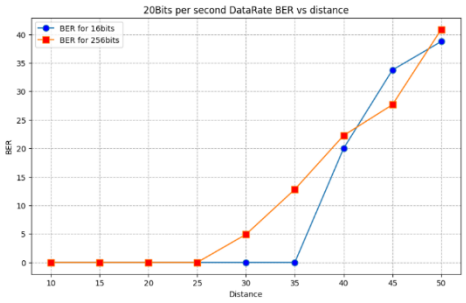

Fig. 28 : SISO 20bps

Fig. 29 : For the SISO system at data rates of 10 bits/s and 20 bits/s had shown significant BER increases with distance. For a 10 bits/s data rate, the BER had increased by 8.75% from 25 cm to 35 cm and by 20% from 35 cm to 50 cm. At 20 bits/s, the BER had risen by 8.75% between 25 cm and 35 cm and by 7.5% from 35 cm to 50 cm.

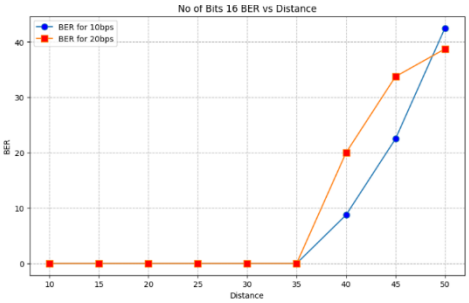

Fig. 29 : SISO 16bits

Fig. 30: For the SISO system, utilizing 256-bit data at data rates of 10 bits/s and 20 bits/s, had revealed a marked increase in BER with greater distances. For the 10 bits/s rate, the BER had grown by 2.65% from 25 cm to 35 cm and by 10.86% from 35 cm to 50 cm. At the 20 bits/s rate, the BER had increased by 4.92% between 25 cm and 35 cm and by 13.20% from 35 cm to 50 cm.

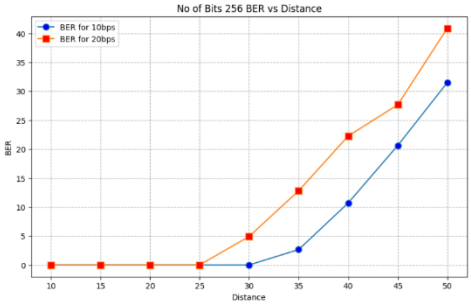

Fig. 30 : SISO 256bits

iii. Comparison of Low Data Rates Vs. High Data Rates for MISO SYSTEM

A. Data Rates and No of Bits (16 bits , 256 bits)

Fig. 31: At a data rate of 80 bits/s, using 16 bits of data, the BER had increased by 2.5% from 25 cm to 35 cm and by 16.25% from 35 cm to 50 cm. In comparison, for 256 bits of data at the same rate, the BER had risen by 1.41% between 25 cm and 35 cm, and by 14.95% from 35 cm to 50 cm. These results had shown that the increase in BER was more pronounced with higher data rates over longer distances, illustrating the impact of data rate on communication reliability in visible light systems.

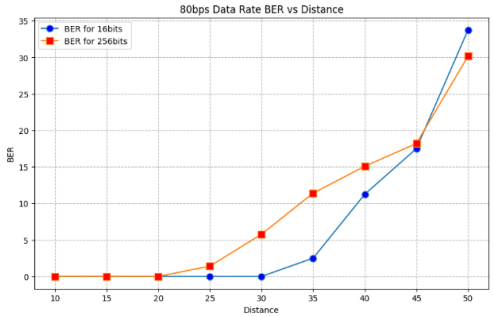

Fig. 31 : 80bps

B. No of Bits and Data Rates (10 bits/s , 80 bits/s)

Fig. 32: For a data size of 16 bits, the BER had demonstrated a noticeable gradient increase with distance for both low and high data rates. At a data rate of 10 bits/s, the BER had risen by 10% from 25 cm to 35 cm and by 18.75% from 35 cm to 50 cm. In contrast, at a higher data rate of 80 bits/s, the BER increase had been more moderate, with a rise of 2.5% from 25 cm to 35 cm and 16.25% from 35 cm to 50 cm. This comparative analysis had shown that while higher data rates had enhanced system performance at shorter distances, the BER had still deteriorated with increasing distance, though less sharply compared to lower data rates.

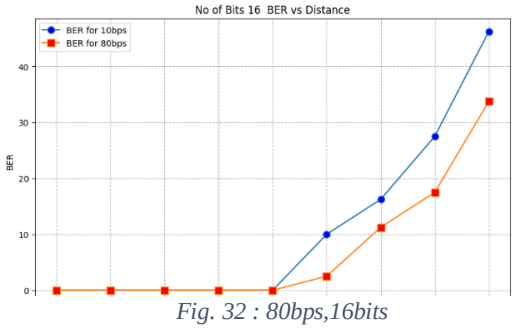

Fig. 32 : 80bps,16bits

Fig. 33: At a low data rate of 10 bits/s, the BER had increased by 6.71% from 25 cm to 35 cm and by 23.05% from 35 cm to 50 cm. For the higher data rate of 80 bits/s, the BER had risen by 5.25% between 25 cm and 35 cm and by 18.24% from 35 cm to 50 cm. This comparison had shown that while increasing the data rate had generally reduced the BER at shorter distances, the BER still deteriorated with distance, though the rate of increase was less significant at higher data rates.

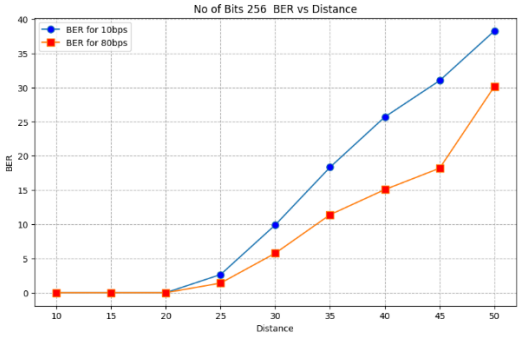

Fig . 33 : 80bps,256 bits

iv. Data Rate Vs. BER for SISO SYSTEM

A. 16 Bits and 256 Bits (50cm)

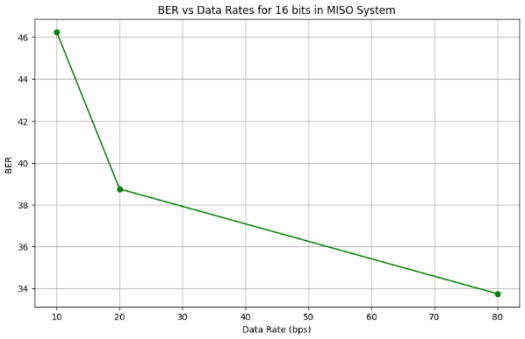

Fig. 34 : SISO 16 bits

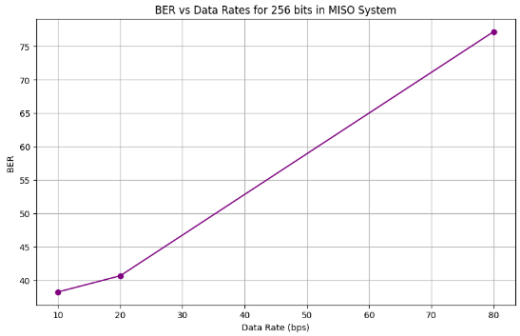

Fig. 35 :SISO 256 bits

v. Data Rate Vs. BER for MISO SYSTEM

A. 16 Bits and 256 Bits (50cm)

Fig. 34, Fig. 36: At a distance of 50 cm, when transmitting a 16-bit data stream, the Bit Error Rate (BER) had shown a decreasing trend as the data rate increased. This trend had indicated that with a short bit stream, the occurrence of errors had been relatively low. As the data rate increased, the BER had decreased, suggesting that the system had managed to

maintain accuracy and reliability even at higher data rates, likely due to the reduced likelihood of errors in a shorter bit stream.

Fig. 35, Fig. 37: In contrast, at the same distance of 50 cm, when transmitting a longer 256-bit data stream, the BER had shown an increasing trend with higher data rates. This indicated that with a longer bit stream, the likelihood of errors had been higher. As the data rate increased, the BER had also increased, reflecting the challenge of maintaining

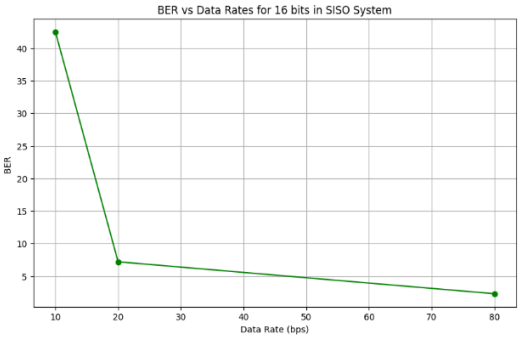

Fig. 36 ; MISO 16 bits

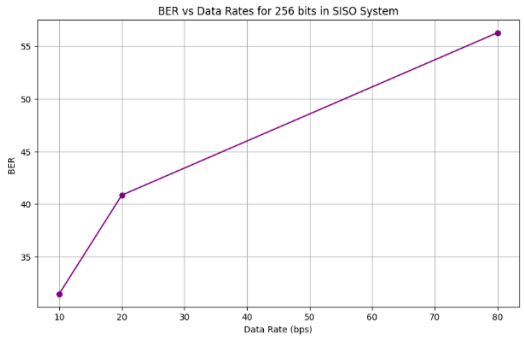

Fig. 37 : MISO 256bits

data integrity over longer transmissions at higher speeds.

vi. Compare the BERs of SISO Vs. MISO Systems

A. 16 Bits and 256 Bits (50cm)

Fig. 38,Fig. 39: While the MISO system had generally been more effective at reducing BER for shorter streams, it had exhibited a steeper increase in BER for longer streams compared to the SISO system. This suggested that although MISO offered higher data rates and better performance for short transmissions, it might have required further optimization for efficiently handling longer data streams.

These findings had emphasized the need for careful balancing of data rate, bit stream length, and system design in VLC systems, especially in scenarios where both speed and accuracy were crucial.

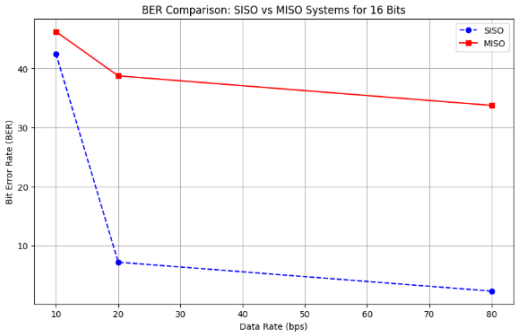

Fig. 38 : 16bits

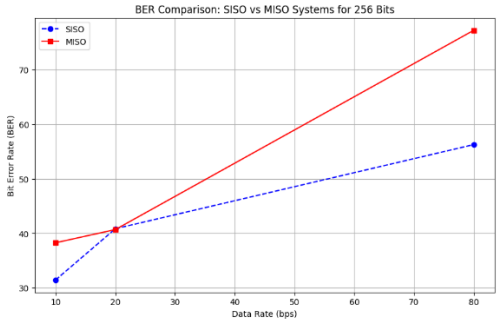

Fig. 39 : 256 bits

vii. Comparison of BERs for different Color MISO Systems

This provides a comparison of BERs across different color MISO systems.

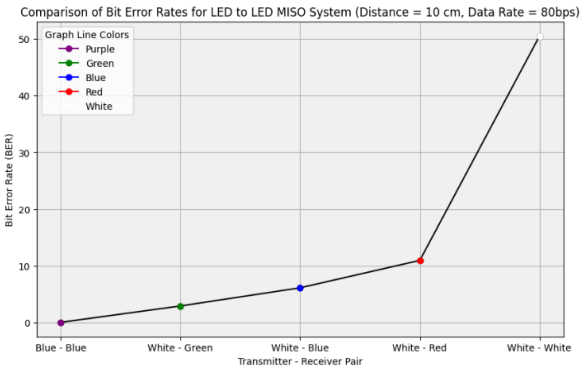

Fig. 40 : Color Comparison of LED to LED

This displays the BERs for various color power LEDs.

Distance = 10cm		BER
Data rate = 80 bps		
Transmitter Side	Receiver Side	
Blue - Blue	Blue	0
White - White	Green	2.890625
White - White	Blue	6.09375
White - White	Red	10.9375
White - White	White	50.546875

Table 03 : Color Comparison Table

viii. Intensity Levels of Different Color LED to LED MISO Systems

This illustrates the intensity levels of various color power LEDs.

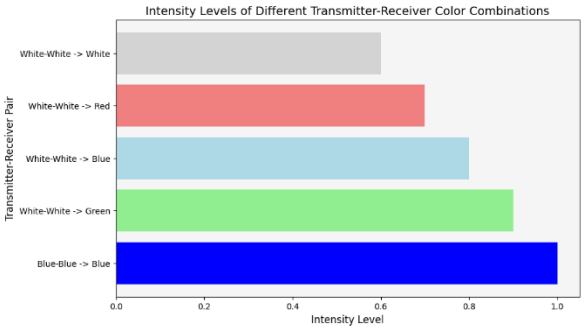

Fig. 41 : Intensity Levels of Different Color Power LEDs

IV. CONCLUSION

Based on the analysis of intensity levels and Bit Error Rates (BERs) in different configurations of the LED-to-LED MISO Visible Light Communication System, it had been, concluded that the MISO system performed better than the SISO system. This was primarily due to the increased data rates achievable with MISO, which was crucial for enhancing communication efficiency in complex environments.

Initially, the project focused on a blue-to-blue MISO system, chosen for the high intensity levels of blue power LEDs. This configuration was ideal for achieving reliable communication in challenging conditions. However, recognizing the significance of white to-white communication in vehicle-to-vehicle systems, such as headlights, the project had been further developed using white power LEDs. White-to-white communication was prevalent in everyday life, particularly in automotive applications where clarity and consistency of signal transmission were critical.

Subsequent modifications had included testing white-to-white, white-to-red, and white to-green configurations. The findings revealed that while blue-to-blue communication had the highest intensity and the best BER, white-to-red and white-to-green MISO systems were crucial for real-world vehicle-to-vehicle applications. These configurations were particularly relevant for functions like brake lights, traffic lights, and other signaling systems where color differentiation was vital for safety and effectiveness.

In conclusion, the project had demonstrated that while blue-to-blue communication excelled in specific scenarios, the versatility and applicability of white-to-white and other color combinations in MISO systems made them indispensable in modern vehicle communication systems. The improved data rates and reliability of MISO systems underscored their importance in enhancing the safety and efficiency of vehicle-to-vehicle communication.

V. ACKNOWLEDGEMENTS

Heartfelt appreciation is expressed to the Head of the Telecommunication Department, Ms. Dilanka De Silva, the project supervisor, for her exceptional guidance and unwavering support throughout this final year project. Her expertise and encouragement have been invaluable in steering the project to its successful completion. Sincere gratitude is also extended to the staff of the Electronics Engineering (EE) Lab and Optical Lab at SLTC for their invaluable assistance and cooperation. Lastly, deep appreciation is conveyed for the contributions and support from all those who played an essential role in the successful completion of the "LED to LED Multiple Input Single Output (MISO) Visible Light Communication (VLC) System" project. Their involvement and encouragement have been vital to this endeavor.

VI. REFERENCES

[1] H. Miawarni and E. Setijadi, "Vlc design and experiment using 650 nm laser transmitter and parallel red diffuse led as receiver," in 2016 IEEE International Conference on Communication, Networks and Satellite (COMNETSAT). IEEE, 2016, pp. 65–68.

[2] M. Kowalczyk and J. Siuzdak, "Vlc link with leds used as both transmitters and photo-detectors," in 2015 Seventh International Conference on Ubiquitous and Future Networks. IEEE, 2015, pp. 893–897.

[3] S. Li, A. Pandharipande, and F. M. Willems, "Adaptive visible light communication led receiver," in 2017 IEEE SENSORS. IEEE, 2017, pp. 1–3.

[4] B. Fahs, J. Chellis, M. J. Senneca, A. Chowdhury, S. Ray, A. Mirvakili, B. Mazzara, Y. Zhang, J. Ghasemi, Y. Miao et al., "A 6-m ook vlc link using cmos-compatible pn photodiode and red led," IEEE photonics technology letters, vol. 28, no. 24, pp. 2846–2849, 2016.

[5] R. Sharma, A. C. Kumari, M. Aggarwal, and S. Ahuja, "Performance analysis of led based indoor vlc system under receiver mobility," in 2017 International Conference on Computing, Communication and Automation (ICCCA). IEEE, 2017, pp. 945–950.

[6] F. A. Umrani, F. A. Dahri, A. W. Umrani, and H. B. Mangrio, "The internet of led: Indoor visible light communication using led as transmitter and receiver," in 2018 21st International Symposium on Wireless Personal Multimedia Communications (WPMC). IEEE, 2018, pp. 75–78.

Smart Driving Assistance System for Expressway Safety

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Abstract - Vehicle to vehicle communication is an emerging advanced technology critical for enhancing road safety and sustainability on highways. By facilitating real-time data exchange between vehicles, it provides essential information about speed, location, and traffic conditions for the drivers, leading to collision prevention and improved traffic management. The aim of the work is to design and develop a smart driving assistance system that leverages wireless communication technology to track and analyze driving parameters on expressways. The product consists of two key subsystems, namely two smart devices i.e. housed in two distinct vehicles and Wi-Fi network to enable peer to peer real-time communication between two smart devices. A smart device is built with Raspberry pi platform, ultrasonic sensor, GPS sensor, accelerometer, Camera and a smart display to interact with the driver with necessary driving parameters such as safe distance from front vehicle, safety check on self overtake and warning on speed limit. The smart device features a voice assistant that delivers real-time commands and driving alerts to the driver. The results show that accidents can proactively be mitigated using the product solutions like maintaining a safe distance from front vehicle and maximum speed limit, checking on "safe to overtake" with image processing technique and exchanging message between two parties with web-socket protocol, with high accuracy.

Key words : Vehicle to Vehicle Communication, Smart Driving Assistance, Real-Time Data Exchange, Web-socket Protocol, Voice Assistance, Driving Parameters Monitoring, Collision Alerts, Full-Duplex Communication, GPS Tracking, Android Application, Doppler Effect

Abbreviations :

V2V: Vehicle to Vehicle
IoT: Internet of Things
GPS: Global Positioning System
MPU6050: Motion Processing Unit 6050
HC-SR04: Ultrasonic Distance Sensor (HC-SR04)
Web-socket: Web-socket Protocol
ECU: Electronic Control Unit
CAN: Controller Area Network
HMI: Human Machine Interface
VANETs: Vehicular Ad Hoc NETworks
SARTRE : Safe Road Trains for the Environment
ITS: Intelligent Transportation Systems

I. INTRODUCTION

This work is dedicated to developing a sophisticated network capable of monitoring and evaluating driving data in real-time through the use of wireless communication technology [1]. The system involves installing smart devices in two separate vehicles, which then communicate with each other over a Wi-Fi network. These devices collect and share crucial driving information, including speed, acceleration, location, and the distance between vehicles. By facilitating this real-time exchange of data, the project aims to significantly enhance communication between vehicles on expressways.

One of the primary objectives of this system is to provide drivers with timely warnings about potential hazards on the road. For instance, if one vehicle detects an obstacle or a sudden change in traffic conditions, this information can be instantly relayed to the other vehicle, allowing the driver to take appropriate action. This kind of proactive communication is designed to encourage safer driving practices, helping to prevent accidents before they occur. In addition to hazard warnings, the system supports better decision making by updating drivers with detailed information about their driving environment. For example, the system can alert drivers if they are exceeding the speed limit, if they are following another vehicle too closely, or if there is a safe opportunity to overtake another vehicle. By integrating these features, the project aims to create a driving assistance network that not only promotes road safety but also enhances the overall driving experience.

Ultimately, the goal of this study is to reduce the number of accidents on expressways by improving the way vehicles communicate with each other. Through the real-time sharing of driving data, the system helps to create a more connected and aware driving environment, where drivers are better equipped to make informed decisions and respond to changing road conditions. This study represents a significant step forward in the development of intelligent transportation systems, with the potential to greatly improve safety and efficiency on the roads.

II. LITERATURE REVIEW

The article [2] discusses the implementation of vehicle-to-vehicle (V2V) communication in a platooning system. The authors suggest that platooning can provide numerous benefits, such as increased safety, reduced fuel consumption, and improved traffic flow. However, platooning requires precise coordination between the vehicle, which can be achieved through V2V communication. A platoon (or road train), according to SARTRE , is a group of vehicles that includes a heavy lead vehicle that is operated by a human, as well as several automatically controlled (both laterally and longitudinally) trailing trucks and/or passenger cars. Here they use CAN (or CAN bus), which is a widely used wired communication bus standard intended to allow communication between automobile devices and micro controllers (also known as nodes or ECUs). A dedicated SARTRE CAN bus is added in the SARTRE prototype

vehicles for linking a group of computer nodes. These nodes are responsible for separate tasks of the platooning applications include HMI, sensor fusion, control algorithms, and V2V. In platooning non-line-of-sight conditions will occur due to different sizes of vehicles and environmental conditions. This implies that careful antenna placement is needed. And the chose CAN network must be wired in topology that limits stubs as much as possible and high cost needed for software development and maintenance.

The study, [3] states the expressway road system is mainly affected by the demand from the new free trade zone and the improvement of efficiency it facilitates. Accidents on expressways are a major concern worldwide due to their potential for causing severe injuries and fatalities. The Southern Expressway in Sri Lanka is no exception. The section provides a detailed review of the existing literature on accidents on expressways, with a specific focus on the Southern Expressway in Sri Lanka. This investigation aims to determine how expressways affect traffic accidents on the roads. Desai and Patel (2011) show safety measures for controlling road accident injuries and fatalities in India. Road accident statics in Gujrat for the years 2000 to 2009 and the road safety policy for the area were analyzed using a fatality index and compared with the Indian average as well as that of other developing counties. Key road safety problems were categorized as driver-vehicle and road-related defects. Ramya (2016) has analyzed and predicted road accidents in Bangalore South. Patterns in data were constructed and a combination of variables that reliably predicts a desired outcome was found. Singh and Suman (2012) introduced a model for accident analysis and prediction on national highways, based on a 70km stretch of NH-77 from Haripur to Muzaffarpur. The data collected between years 2000 and 2009 were analyzed to evaluate the effect of influencing parameters.

The paper titled [4], addresses the use of real-time vehicular traffic information to improve routing in VANETs in urban environments. The authors propose a new routing approach (RBVT, Road based using vehicular traffic information) that uses a distributed architecture to collect and disseminate traffic information, allowing for more efficient and accurate routing decisions. To implement their proposed system, the authors use a distributed architecture consisting of three layers: the vehicular layer, the roadside layer, and the infrastructure layer. Each layer is responsible for collecting and disseminating traffic information in real-time. It concludes with a discussion of future research directions, such as the integration of additional data sources and the development of more sophisticated routing algorithm.

III. MOTIVATION

The increasing complexity of modern expressways, coupled with the high volume of vehicles, has significantly elevated the risk of traffic accidents [6]. Traditional methods of ensuring road safety, such as static signage and reactive driver assistance systems, are proving insufficient to meet the demands of today's fast-paced driving environment. The lack of real-time, reliable communication between vehicles exacerbates the problem, often leading to hazardous collisions that could have been avoided with timely intervention.

The "Smart Driving Assistance Network" is motivated by the urgent need to integrate such advanced technologies into the existing vehicular infrastructure, particularly on expressways where high speeds demand quick and accurate decision-making from drivers. By leveraging wireless communication and image processing techniques, this work aims to create a system that not only monitors driving parameters but also provides real-time alerts to drivers about potential hazards. This proactive approach to road safety is crucial in reducing the time it takes for drivers to respond to dangerous situations, ultimately saving lives. Another driving factor behind this work is the potential to enhance the efficiency of expressways. Traffic congestion and accidents often lead to significant delays, affecting not only individual drivers but also the economy at large. By enabling vehicles to communicate with each other and share critical information, the system aims to create a more synchronized flow of traffic, reducing bottlenecks and improving overall traffic management.

The integration of IoT and smart devices further opens up possibilities for future innovations, such as automated driving and smart city applications, making this project a stepping stone toward a more connected and safer transportation network. the study is motivated by the desire to contribute to the body of research in the field of intelligent transportation systems (ITS). As cities grow and urbanization intensifies, the demand for sustainable and safe transportation solutions becomes increasingly pressing [7]. This research aims to address some of the challenges in ITS, particularly in the context of real-time vehicle-to-vehicle communication and smart driving assistance. The insights gained from this work could inform future developments in the field, paving the way for more sophisticated and effective safety systems on roads worldwide.

IV. METHODOLOGY

i. Solution Diagram

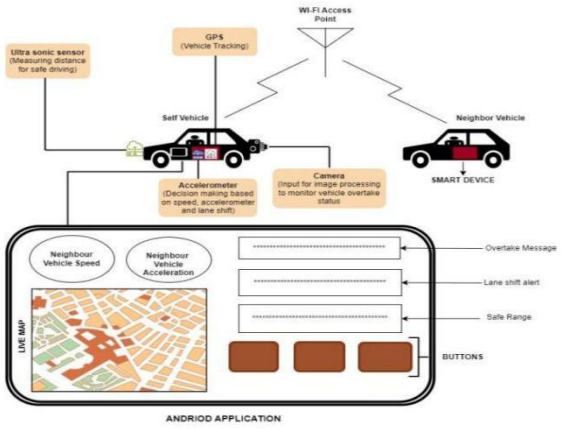

Figure 1: Solution Diagram

Figure 1 presents a comprehensive solution diagram that visually represents the integration of various sensors within the Smart Device, both in the vehicle itself and in neighboring

vehicles. This diagram highlights the seamless interaction between the hardware components and the software application interface, emphasizing how these elements work together to enhance driving safety and decision-making. The diagram not only shows the physical layout of the system but also underscores the importance of real-time data processing and context-aware alerts in promoting safe driving practices. This holistic approach to vehicle communication and driver assistance represents a significant advancement in intelligent transportation systems, with the potential to greatly improve safety and efficiency on the roads.

ii. System Architecture

Figure 2 shows how driving parameters are measured using the sensors while vehicle positions at the rear end are detected with a camera. The collected data is processed by a Raspberry Pi and is subsequently distributed in two primary ways such as Real-Time Driver Assistance, where one portion of the data is used to provide real-time assistance on driving conditions through an application, with voice guidance included. Data from the accelerometer, GPS, ultrasonic sensor, and real-time video capture from the camera is retrieved and analyzed to inform the driver about a safe driving range. The Point-rend pre-trained model is utilized for video segmentation, and the Pixel-lib library is employed for detecting vehicle positions based on lane information. And Vehicle-to-Vehicle Communication, where other portion of the data enables communication with other drivers via Wi-Fi using Web-socket protocol (Real time data transfer). Access for additional smart devices is facilitated by local servers hosted on these devices, allowing for the sharing of driving parameters between connected systems.

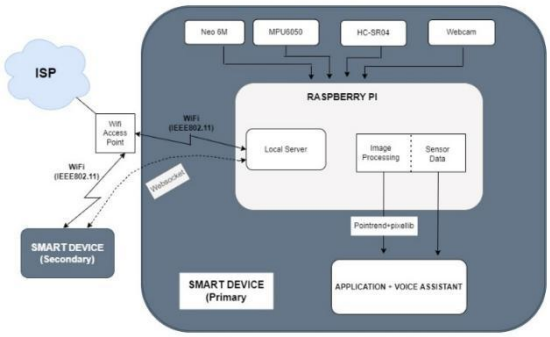

Figure 2: System Architecture

V. SYSTEM MODEL

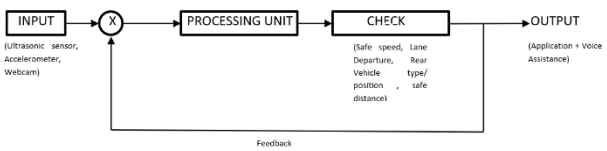

Figure 3: Block diagram for Collision Prevention Algorithm

The collision prevention algorithm is a sophisticated system that integrates multiple data sources to provide real-time hazard detection and alerts. By continuously monitoring speed, distance, lane deviation, and rear-end threats, the algorithm ensures that the driver is aware of potential risks. The real-time feedback loop allows for quick re-evaluation of the driving conditions, maintaining system reliability and ensuring safe driving on expressways. The system's use of parallel data processing ensures that alerts are timely, while its continuous monitoring guarantees that hazards are identified as soon as they emerge.

COLLISION PREVENTION ALGORITHM

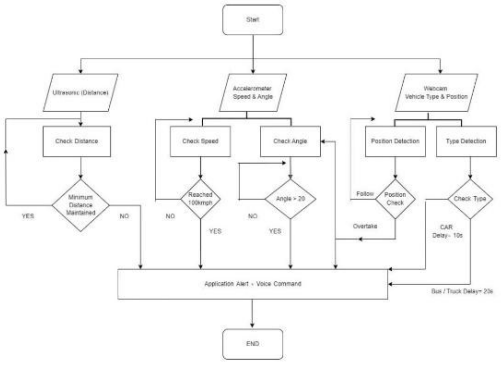

Figure 4: Operational Flow of the Collision Prevention Algorithm

The operational flow of the developed driving assistance system begins with the initialization of all hardware components, including the Raspberry Pi, ultrasonic sensor (HC-SR04), accelerometer (MPU6050), and rear-end camera. These devices continuously gather critical data such as the distance to the vehicle in front, vehicle speed, lane deviation, and rear vehicle behavior. The system processes this data using a collision prevention algorithm, which assesses four key safety parameters: maintaining a safe following distance, driving at a safe speed, avoiding lane deviation, and identifying rear-end threats, such as vehicles attempting to overtake. Based on this real-time analysis, the system issues alerts via a smart display and voice assistance if any safety thresholds are breached. Alerts include speed adjustment warnings, lane deviation alerts, and warnings related to overtaking threats.The system adjusts rechecking intervals based on the type of rear-end vehicle (e.g., car, bus, or truck) and continually updates the vehicle's safety status, providing ongoing feedback and ensuring proactive driving assistance.

A. System Design and Sensor Integration

In the development of the smart driving assistance network, an embedded system was designed and integrated with several key sensors, including the HC-SR04 ultrasonic sensor, NEO-6M GPS module, MPU6050 accelerometer, and a camera. These sensors collectively enabled the smart device to monitor critical driving parameters and provide real-time feedback to the driver. The following sections describe the role of each sensor in the system:

a) Collision Warning

The HC-SR04 ultrasonic sensor is utilized to measure the distance between the vehicle on which the device is mounted

and any obstacle or vehicle in front [8]. This distance measurement is crucial for advising the driver on the safe distance that should be maintained from the vehicle ahead. By continuously monitoring this distance, the system can alert the driver if they are too close to the preceding vehicle, thus helping to prevent collisions. Recognizing the potential impact of the Doppler effect due to high-speed vehicle movement on highways, the system incorporates adjustments to account for these variations in distance measurements. This ensures that the distance calculations remain accurate even under the influence of relative motion between vehicles, enhancing the reliability of the safety alerts provided to the driver.

Doppler Effect Calculation
F0= 40,000Hz (Ultra sonic sensor frequency)
V1=80km/h
V2=100km/h
C=343m/s

1. Relative Velocity

$$Vrel = V2-V1$$
$$=100km/h - 80km/h$$
$$=20km/h$$

2. Observed Frequency

$$F= FO \left(\frac{C+Vrel}{C}\right)$$
$$= 40,000 \left(\frac{343+5.55}{343}\right)$$
$$= 40,000 (1.016)$$
$$= 40,640Hz$$

Assuming measured TOF is 0.01s
Without Doppler effect, the distance d is,

$$d = c \times \frac{0.01}{2}$$
$$= 343 \times \frac{0.01}{2}$$
$$= 1.715m$$

Without Doppler effect, we consider adjusted speed of sound C'

$$C' = C + Vrel$$
$$=343+5.5$$
$$=348.5\ m/s$$

Adjusted distance d'

$$d' = c' \times \frac{TOF}{2}$$
$$= 348.5 \times \frac{0.01}{2}$$
$$=1.7425m$$

Distance measurement considering Doppler effect is higher than initial calculation,

1.7425 > 1.715

b) Speed Assist, Lane Departure Warning

The MPU6050 sensor is used to measure the speed of the vehicle. This data is essential for informing the driver about their current speed and whether they are exceeding the speed limit on highways. The sensor's accelerometer and gyroscope functionalities also enable the detection of angular shifts [9]. This capability is particularly important when the system issues a warning advising the driver not to change lanes. If a lane change is detected despite the warning, the system re-alerts the driver, emphasizing the importance of maintaining the correct lane position.

c) Live Location Update

The NEO-6M GPS module is employed to track the vehicle's position on expressways. The GPS data allows the system to detect whether the vehicle is stationary or moving, providing critical information to the driver, especially in traffic congestion scenarios. The GPS data also facilitates the identification of the direction of message exchange between vehicles, enabling the driver to discern whether messages are originating from vehicles ahead or behind [10]. This feature enhances situational awareness and helps in making informed driving decisions.

B. *Image Processing and Vehicle Detection*

The image processing component of the smart driving assistance system is designed to enhance driver awareness by analyzing video input captured from a rear-mounted camera on the vehicle. Utilizing the Point-rend pre-trained model, the system identifies and classifies approaching vehicles on expressways, distinguishing between different types such as cars, trucks, and buses [11].

Figure 2: Vehicle Type and Vehicle Position Detection

This classification enables the system to issue alerts of varying duration based on vehicle type, with larger vehicles like trucks triggering longer alerts to prevent lane changes until it is safe. Additionally, the system includes custom-developed libraries to analyze the position of the approaching vehicle, determining whether it is following, preparing to overtake, or actively overtaking. This analysis allows the smart device to issue timely alerts to the driver, advising against lane changes when an overtaking vehicle is detected, thereby significantly enhancing road safety by preventing potential accidents.

C. Application Development with Voice Assistant

The developed Android application serves as a comprehensive interface for the smart driving assistance system, integrating several key components to enhance driver safety and convenience. The application features a display that presents real-time data, including speed, acceleration, and messages received from other smart devices. A map interface provides visual navigation and location tracking, while alert notifications are issued for critical parameters such as minimum safe distance, maximum speed, and lane shift warnings. The application also includes functionality to alert the driver if they attempt to change lanes while a lane shift alert is active. Additionally, it allows for communication with other smart devices through buttons for sending "Overtake" and "Follow" messages, as well as a connect button to establish and manage device connections. To further enhance driver assistance, the application is equipped with a speaker that delivers voice commands and alerts, ensuring that drivers can receive important information without the need to look at the screen. This audible feedback is designed to be more efficient than visual observations, particularly on expressways, thereby contributing to a safer driving experience by keeping the driver focused on the road.

Figure 3: Software Application with voice assistant

D. *Full Duplex Communication*

The system employs a full-duplex communication model between smart devices using Web-socket protocol over Wi-Fi, enabling bidirectional and real-time data exchange [12]. This setup allows the devices to continuously communicate driving parameters such as speed, acceleration, overtake/ follow messages, and location measurements, ensuring that drivers remain informed and can make well-informed decisions. The Web-socket protocol is chosen for its efficiency in providing secure and reliable communication, supporting the seamless exchange of information between devices. This protocol facilitates instantaneous updates and interactions, enhancing the effectiveness of the smart driving assistance system by ensuring that critical data is exchanged without delay, thus contributing to improved road safety and driver coordination.

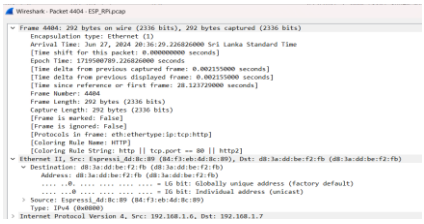

Figure 4: Message Latency Analysis

The Wire-shark tool, has been used to analyze a detailed measure of the latency in communication within the Smart Driving Assistance Network. By capturing network frames, the arrival time of the GET message and its corresponding acknowledgment have been identified to calculate the round-trip time. The observed latency in this communication was approximately 8.176 milliseconds. This low latency is critical for ensuring timely data exchange between vehicles, enabling real-time decision-making and providing immediate alerts to drivers about potential overtaking situations or other driving conditions. The latency achieved aligns well with the requirements for vehicular communication systems, where minimizing delay is essential for safety and effective coordination on expressways.

VI. RESULTS AND DISCUSSIONS

This section presents the outcomes achieved through the development and implementation of the "Smart Driving Assistance" system. The approach successfully integrated several advanced technologies to enhance driving safety, improve situational awareness, and facilitate effective vehicle-to-vehicle communication on highways. The primary outcomes are discussed below:

1. *Implementation of the Embedded System for Capturing Driving Parameters*

Successful implementation of an embedded system using multiple sensors, including the ultrasonic sensor (HC-SR04), accelerometer (MPU6050), and GPS (NEO 6M), to capture critical driving parameters such as safe distance, acceleration, speed, and location. The embedded system was deployed on a Raspberry Pi, enabling real-time data acquisition and processing.

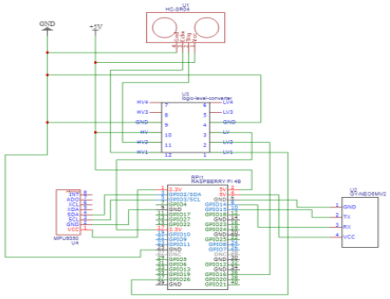

Figure 5: Schematic Diagram of the Smart Device

The HC-SR04 ultrasonic sensor provided accurate distance measurements between vehicles, a crucial factor in determining safe following distances. The sensor's

integration with the Raspberry Pi allowed for real-time distance alerts, ensuring prompt driver responses to potential collisions. The MPU6050 accelerometer was effectively utilized to measure vehicle speed and acceleration. This data was processed in real-time to provide immediate feedback to the driver regarding their driving habits, promoting safer driving behavior. The NEO 6M GPS module enabled accurate location tracking, providing continuous updates on the vehicle's geographic coordinates. This functionality was vital for the live map feature in the software application, which assists the driver in understanding their position relative to the road and other vehicles. The embedded system demonstrated reliable performance, consistently providing accurate and real-time data essential for driving assistance.

2. *Deployment of Image Processing for Real-Time Overtaking Detection*

Advanced image processing techniques were employed to enhance the system's situational awareness. Using the PointRend model, the software application could segment real-time images captured from the rear-end camera to identify and classify different types of vehicles.

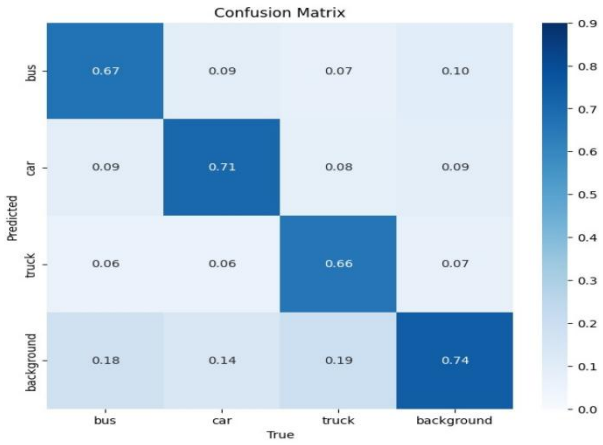

Figure 6: Image Processing Performance Measurement

METRIC	DESCRIPTION	VALUE
ACCURACY	AVERAGE	86%
PRECISION	AVERAGE	74%
RECALL	AVERAGE	68%
SPECIFICITY	AVERAGE	92%

Figure 7: Image Processing Evaluation Summary

The PointRend model, integrated with the PixelLib library, was used to perform image segmentation, allowing the system to detect vehicles approaching from behind. The segmentation process accurately identified vehicles such as cars, trucks, and busses, which is crucial for determining potential overtaking situations. By analyzing the segmented images and tracking vehicle positions relative to the user's vehicle, the system could accurately detect overtaking scenarios. This feature significantly improves driver awareness, especially in high-traffic conditions, by providing real-time alerts through the software application. The deployment of image processing techniques demonstrated the ability to enhance situational awareness by accurately detecting overtaking vehicles, thereby reducing the risk of collisions.

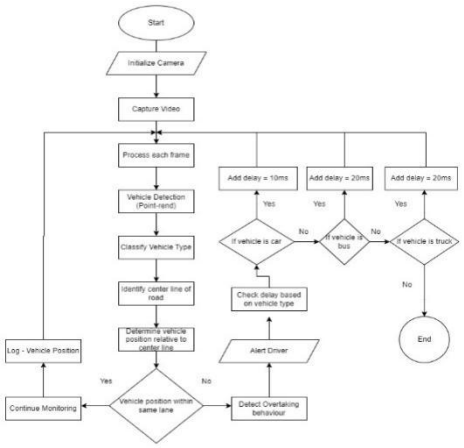

Figure 8: Operational Flow of the Image Processing Technique

This classification enables the system to issue alerts of varying duration based on vehicle type, with larger vehicles like trucks triggering longer alerts to prevent lane changes until it is safe. Additionally, the system includes custom developed libraries to analyze the position of the approaching vehicle, determining whether it is following, preparing to overtake, or actively overtaking. This analysis allows the smart device to issue timely alerts to the driver, advising against lane changes when an overtaking vehicle is detected, thereby significantly enhancing road safety by preventing potential accidents.

3. *Development of a Software Application with Integrated Voice Assistance*

A comprehensive software application was developed to provide a user-friendly interface for visualizing sensor data and facilitating seamless communication between vehicles. The application was designed to run on a smart device and included a real-time voice assistant feature to deliver critical driving updates.

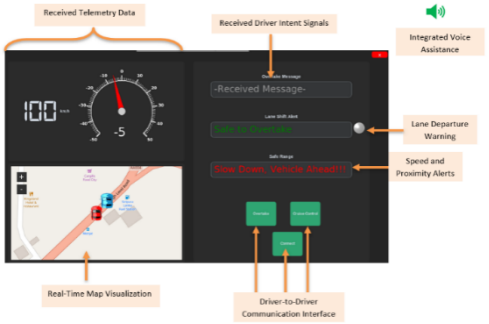

Figure 9: Interface of the Application

The application provides real-time visualization of sensor data, including speed, acceleration, safe distance, and location. This feature allows drivers to monitor their driving parameters continuously and make informed decisions. The integrated voice assistant dynamically informs the driver about potential hazards, overtaking chances, and other critical

notifications. This feature enhances the driver's situational awareness and ensures that they remain focused on the road. The application includes a live map feature for real-time location tracking and an intuitive interface that allows drivers to send and receive messages with other drivers, promoting cooperative driving behavior. The development of the software application, combined with the voice assistant, provided an effective platform for integrating various driving assistance features, thus improving overall driving safety.

4. *Enabling Communication Between Drivers Using Smart Devices*

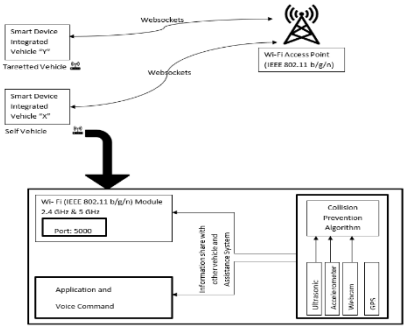

Figure 11: Block diagram of the full duplex communication

A robust wireless network was implemented to enable effective communication between drivers using smart devices. This network was built using WebSocket protocols over WiFi, allowing for low-latency, real-time message exchange between vehicles. The use of WebSocket protocols ensured a reliable and low-latency communication link between vehicles. Drivers can send predefined messages such as "overtake" and "follow" to other drivers, enhancing coordination and safety on the road. The communication system proved to be efficient in providing timely alerts and facilitating cooperative driving behavior, making it a vital component of the overall driver assistance system.

The results demonstrate that “Smart Driving Assistance Network For Expressways” has successfully achieved its objectives by integrating embedded systems, advanced image processing, a comprehensive software application, and robust wireless communication. These components work together to provide real-time driving assistance, enhancing safety and promoting cooperative driving. Future work could focus on optimizing the processing speed for real-time image segmentation on low-power devices like the Raspberry Pi, as well as expanding the system's capabilities to include more complex driving scenarios and machine learning models for predictive analysis.

The driving assistance system underwent extensive real-time testing in real-world conditions to assess its performance and reliability. For image processing, the rear-end camera was mounted on the vehicle's roof, enabling accurate detection and classification of approaching vehicles. To test other functions, such as obstacle detection and speed monitoring, the device was positioned at the front of the vehicle, ensuring precise readings from the ultrasonic sensor and speed sensor. These configurations allowed the system to be tested effectively, demonstrating its readiness for deployment in various driving environments.

Figure 12: Real Time Test – Image Process

The first phase of testing involved real-time image processing to detect and categorize vehicles approaching from the rear. Through the use of a rear-end camera, the system successfully identified vehicle types, such as cars and trucks, and tracked their positions relative to the host vehicle. The system demonstrated a high degree of accuracy in determining when vehicles were overtaking or following closely, enabling the timely generation of alerts for the driver. This real-time detection of rear-end vehicle movement is crucial for enhancing driver awareness and safety, particularly in high-speed expressway environments.

Figure 10: Real Time Test – Safe Distance

In the second phase, the system's obstacle detection functionality was tested using an ultrasonic sensor to monitor the distance to objects in front of the vehicle. The system accurately detected obstacles at varying distances and issued warnings to the driver in real time. This capability is essential for collision avoidance, especially in congested or fast-moving traffic. Furthermore, the system’s speed measurement component was evaluated by comparing the real-time speed data with the vehicle's actual speedometer readings. The results showed precise synchronization, allowing the system to assign a maximum safe speed for expressway driving. This ensures that the vehicle operates within safe limits, reducing the likelihood of accidents due to excessive speed.

Figure 13: Real Time Test – Maximum Speed

Overall, the system demonstrated robust performance in detecting both rear-end and front-end driving conditions, while effectively communicating critical information to the driver. The integration of real-time image processing, obstacle detection, and speed monitoring allows for comprehensive driving assistance that enhances safety and situational awareness. The successful communication between vehicles using the system's smart device network further amplifies its potential for real-world application, particularly in expressway and highway environments where timely decision-making is crucial for driver safety.

The Smart Driving Assistance System offers versatile applications that significantly enhance road safety, improve traffic management, and support the development of autonomous driving technologies. By leveraging real-time communication and advanced detection capabilities, the system effectively addresses critical transportation challenges for both individual drivers and commercial fleets. One of its key applications is in highway safety, where real-time overtaking alerts improve lane change safety at high speeds. This feature helps reduce accidents caused by driver blind spots and delayed reactions. Additionally, in the realm of commercial logistics, the system enhances fleet management by enabling real-time communication and monitoring among drivers, promoting safer maneuvers, optimizing fuel efficiency, and ensuring adherence to safety protocols. Furthermore, for semi-autonomous and autonomous systems, vehicle-to-vehicle (V2V) communication enhances cooperative driving by providing synchronized insights into vehicle speed and position, which is essential for effective coordination between human-driven and autonomous vehicles.

Beyond its benefits for individual drivers and fleets, the system's real-time hazard detection offers critical advantages in both urban and highway settings. By allowing drivers to respond proactively to sudden obstacles, the system plays a vital role in preventing chain-reaction collisions, particularly in high-traffic areas. It also supports emergency response efforts by relaying priority path information for vehicles like ambulances, ensuring faster transit and facilitating dedicated lane discipline around emergency zones. Through these diverse applications, the Smart Driving Assistance System addresses essential safety and efficiency needs in modern transportation. By fostering real-time communication and proactive hazard detection, it establishes a foundation for safer highways, optimized fleet operations, and seamless integration with autonomous driving technologies, marking a significant step toward a future of intelligent, interconnected transportation networks. Furthermore, advancements in global server connectivity and IoT integration enhance data sharing and network responsiveness, while the addition of voice commands enables live, interactive driver engagement.

VII. CONCLUSION

The development and implementation of the smart driving assistance system represent a significant advancement in vehicle-to-vehicle communication and road safety technologies. By integrating various sensors including the HC-SR04 ultrasonic sensor, NEO-6M GPS module, MPU6050 accelerometer, and a camera along with a sophisticated Android application, the system effectively monitors critical driving parameters and enhances situational awareness. The use of the Point-rend model for real-time vehicle detection and the Web-socket protocol for full-duplex communication enables seamless data exchange between vehicles, contributing to more informed driving decisions and improved safety on expressways.

The incorporation of voice commands further enhances the user experience, allowing drivers to receive critical alerts without diverting their attention from the road. Future improvements, such as the integration of IoT technologies, edge computing for speed calculations, and the establishment of a global server for secure management, promise to advance the system's capabilities and performance even further. Collectively, these innovations lay a strong foundation for the development of more intelligent, responsive, and secure driving assistance systems, ultimately contributing to safer and more efficient road travel.

VIII. REFERENCES

[1] M. A. a. C. S. a. M. Y. Naeem, "Road to Efficiency: V2V Enabled Intelligent Transportation System," *Electronics*, vol. 13, no. 13, 2024.

[2] C. H. E. &. S. D. Bergenhem, "Vehicle-to-Vehicle Communication for a Platooning System," *Procedia - Social and Behavioral Sciences*, vol. 48, pp. 1222-1233, 2012.

[3] E. a. E. A. Edirisinghe, "Analysis of accidents on the Southern Expressway," 2017.

[4] J. a. R. N. a. W. G. a. B. C. Nzouonta, "VANET routing on city roads using real-time vehicular traffic information," *IEEE Transactions on Vehicular technology*, vol. 58, pp. 3609-3626, 2009.

[5] N. V. S. Gaurav Sharad Patil, "Vehicle To Vehicle Communication," 2016. [Online]. Available: https://ijcat.com/admin/uploads/ijcatrthesis10082018072609-ijcatr20181001.pdf. [Accessed 2022].

[6] S. B. a. P. Saha, "Evaluation of risk factors for road accidents under mixed traffic: Case study on Indian highways," *IATSS Research*, vol. 46, no. 4, pp. 559-573, 2022.

[7] C. Chiancone, "Urbanization and its Impact on Cities," [Online]. Available: https://www.linkedin.com/pulse/urbanization-its-impact-cities-chris-chiancone/. [Accessed 2024].

[8] A. a. K. J. G. a. M. O. O. a. A. J. a. U. B. a. A. O. I. Aliyu, "An ultrasonic sensor distance induced automatic braking automobile collision avoidance system," in *2017 IEEE 3rd International Conference on Electro-Technology for National Development (NIGERCON)*, 2017.

[9] J. I. a. B. d. R. Á. a. D. R. N. C. a. d. M. F. E. Venceslau de Souto, "Design and Implementation of an Embedded Data Acquisition System for Vehicle Vertical Dynamics Analysis," *Sensors*, vol. 23, 2023.

[10 J. M. M. a. O. N. N. Khin, "Real-time vehicle tracking system using Arduino, GPS, GSM and web-based technologies," *International Journal of Science and Engineering Applications*, vol. 7, 2018.

[11] A. a. W. Y. a. H. K. a. G. R. Kirillov, "Pointrend: Image segmentation as rendering," in *Proceedings of the IEEE/CVF conference on computer vision and pattern recognition*, 2020.

[12] A. Diaconu, "The WebSocket API and protocol explained," 5 December 2023. [Online]. Available: https://ably.com/topic/websockets. [Accessed February 2024].

Sustainable Agriculture, Environment (Environment)

Assessment of Land Use Changes on Vegetation Dynamics in Muthurajawela Wetland: A GIS-Based Spatio-Temporal Study

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***Abstract*— Urban wetland ecosystems deliver numerous ecological, social, and economic benefits but are profoundly affected by urbanization and other human-induced activities. So, this study aimed to investigate the influence of the buildup of surface temperature and green cover on the surface in the Muthurajawela wetland, an urban wetland in Sri Lanka that provides essential ecosystem services. This study was conducted based on a point-based analysis from 2014 to 2024. The vegetation loss and urbanized areas were higher temperature areas at the study site. Pearson correlation was used to assess the spatial relationships between surface temperature, Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI), and Normalized Difference Built-up Index (NDBI). Surface temperature negatively correlates with NDVI` (-0.161) and positively correlates with NDBI (0.100). Additionally, correlations among climatic variables showed a weak negative correlation between temperature and relative humidity (-0.261) and a weak positive correlation between temperature and precipitation (0.243). In contrast, relative humidity exhibited a strong positive correlation with precipitation 0.624). These findings highlight the importance of enhancing vegetation cover and implementing sustainable urban planning strategies to mitigate environmental stressors and protect the ecological integrity of the wetland. Developing dense, evenly distributed vegetation and sustainable urban planning and wetland conservation are proposed as key strategies to mitigate vegetation loss in the Muthurajawela wetland area.**

Keywords—Muthurajwela Wetland, spatial and temporal, climate change, land surface temperature, Normalized Difference Vegetation Analysis, Normalized Difference Built-up Indexes

I. INTRODUCTION

The increase in global population directly causes urbanization and the reduction of wetland ecosystems in the global context. Population growth is predicted to reach 9 billion in 2050 [1]. The wetlands account for 4–6% of the world's surface areas and provide a wide range of ecosystem services [2]. Urban lands experiencing exponential growth more than urban population growth cause wetlands biodiversity losses and global and local climatic systems [3]. Extreme anthropogenic temperature variation, loss of green cover, and exponential growth of the urban population and urbanization impacted the development stress environment [4].

Muthurajawela wetland, recognized as the largest saline peat bog in Sri Lanka, forms an interconnected coastal wetland ecosystem with the Negombo estuary [5]. Due to its unique geographical and biophysical features, the Muthurajawela wetland provides essential ecosystem services, including flood control, water filtration, carbon storage, and serving as a breeding and nursery habitat for fish [6]. The estimated annual monetary value of the wetland is approximately Rs 726.5 million [2]. Muthuruajawela wetland is situated in an area of fast expanding and highly populated, making it a highly valuable and vulnerable ecosystem [5]. Thus, assessing changes in land use and vegetation cover within the wetland is essential for preserving its ecological integrity.

The remote sensing and censoring platforms in earth observation provide spatial and temporal scale data. Land Surface Temperature (LST) is defined based on thermal remote sensing technology used to capture emitted thermal radiation from the ground. Various indices are extracted from satellite imageries under the 3 -5µm and 8 -14µm wavelengths [7]. Normalized Difference Vegetation Indexes (NDVIs) and Normalized Difference Built-up Indexes (NDBIs) were generated through remote sensing technology.

The vegetation index analysis provides vegetation cover analysis and distribution in specific areas. This tool is essential for monitoring vegetation dynamics, land cover changes, and ecosystem health [8]. Important factors of analysis of high and low vegetation cover determine the productivity of the vegetation cover. The impact of land use and land cover changes on climate change should be assessed. Impact and impact on human [9]. Based on these factors, properly implementing conservation strategies is essential for preserving the ecology. A sustainable approach to the decision-making process for land management provides possible insight into outcomes in vegetation cover analysis [9].

II. Materials and Methodology

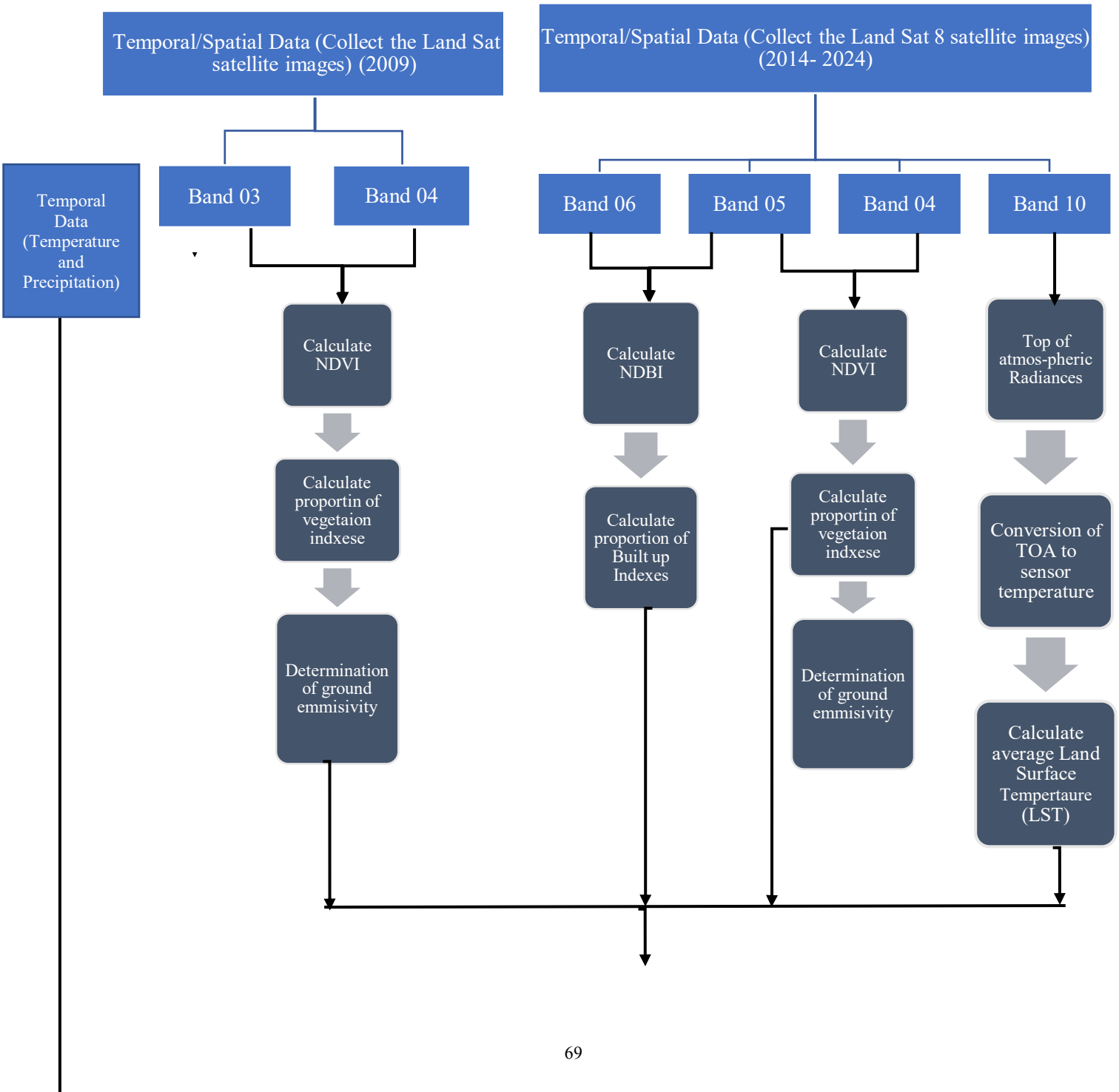
A. Study Site

The Muthurajawela wetland, situated at coordinates 7°6'11.10" N and 79°51'41.85" E, extends from the Negombo lagoon in the north to the Kelani River in the south, reaching inland to Ragama and Peliyagoda in the Gampaha district [6]. In July 1996, the Sri Lankan government designated 1,777 hectares of this wetland as a sanctuary [6]. The landscape of Muthurajawela includes diverse land surface features such as lagoons, marshes, mangroves, and areas of both high and moderate urbanization [2].

B. Data collection

Data was collected to analyze the spatial variation and changes in vegetation cover. The data were collected from the USGS (United States Geological Survey) database [10].

III. Experimental Procedure



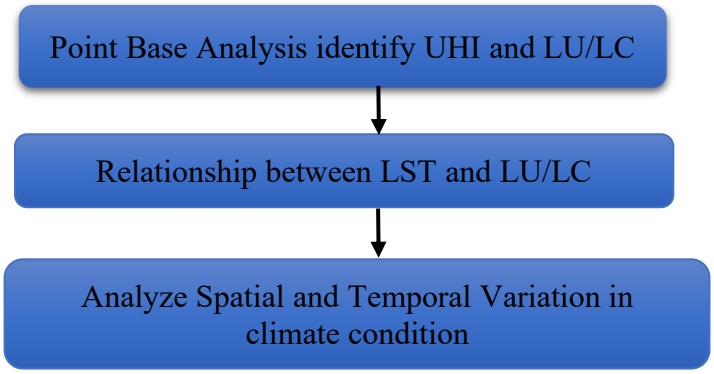


Fig 1-Process flow diagram

C. Land Surface Temperature (LST) Analysis

The main objective of land surface temperature analysis was conducted using the data set collected from the USGS database. Acquired data sets Band-10 (Land Sat 08) and Band-06 (Land Sat 05) were used for TOA retrieving, and Band-5/ Band-4 and Band-03/Band-04 are used for NDVI calculation for Emissivity correction [11]. Data was acquired under three different periods, during which metadata values changed during the analysis.

1) Retrieving Top Atmospheric Radiance (TOA)

Based on Land Sat 8 (OLI) TIR and Land Sat 5 (TM) satellite imagery collection: the algorithm was selected to use metadata set Band 10/Band 06 spectral TIFF file retrieving top atmospheric radiance [10].

$$L\lambda = ML * Qcal + AL - Oi, \quad (1)$$

Where;

$L\lambda$ -Top Atmospheric (TOA) spectral radiance
ML - Specific multiplicative band rescaling factor
Qca – Band 10 Image
AL – Rescaling factor for specific Band
Oi, - Band 10/6 Correction

2) Sensor Temperature Radiance Conversion

Conversion of the radiance to the temperature was obtained from the UHI intensity of the experimental site. Metadata was acquired to analyze the TIRS band data for algorithmic radiance conversion to the brightness temperature (BT) calculation [12].

$$BT = K2 \ln [(K1/L\lambda) + 1] - 273.15 \quad (2)$$

Where;

K1 = Constant Band 10
K2 = Constant Band 10
$L\lambda$ = Top Atmospheric Radiance
-273.15 = Absolute zero Celsius

3) Calculating the NDVI Emissivity Correction method.

The amount of vegetation present in near-infrared factors for highly related factors was calculated in normalized different vegetation indexes analysis [10]

NDVI (Land Sat 8) = (NIR (band 5) - R (band 4)) / (NIR (band 5) + R (band 4)) (3)

Where;

NIR = Near Infrared Radiance
R = Red Band

4) Calculate the vegetation proportion.

The amount of vegetation proportion provided values was calculated to determine the emissivity calculation. NDVI proportion analysis determines the LST values to determine the UHI intensity [13].

5) Calculating Land Surface Emissivity.

The LST intensity analysis process, vegetation, and soil emissivity variables were used to determine land surface emissivity. The radiance emitted and thermal efficiency transmitting thermal energy across the atmosphere's surface were predicted based on the black body (Planck's law) [14].

$$\varepsilon\lambda = \varepsilon V\lambda PV + \varepsilon s\lambda (1\text{-}PV) + C\lambda \quad (4)$$

Where;

εV = Vegetation emissivity
εs = Soil emissivity
C = Represents the surface roughness (0.05)

6) LST extraction

The emissivity-corrected land surface data were retrieved based on temperature readings in Celsius values [14]. The temperature values in Celsius were determined to identify the impact of UHI on the site.

$$Ts = BT/ (\{1 + [(\lambda BT/\rho) \ln \varepsilon\lambda]\}) \quad (5)$$

Where;

Ts = LST Celsius
BT = Sensor BT (Celsius)
λ = Limiting Wavelength (10.895)
Eλ = emissivity calculation

D. NDVI Normalized Difference Vegetation Indexes (NDVI) Computation.

Analysis was conducted through the ArcGIS software version 10.8. Vegetation indexes were obtained to determine the analyses the impact appears due to the anthropogenic activities. NDVI development was produced in Land Sat 05 NIR band-3 with red band-04, which was used for NDVI analysis. An Infrared spectral (IR) - 5 Band with Land 8 OIL (TIRS) Red band-4 makeup and modified to the NDVI analysis [15].

NDVI (Land Sat 08) = (IR Band (5)-R Band (4))/(IR Band (5) + R Band (4)) (6)

NIR = Near Infrared Radiance
R = Red Band

E. Normalized Different Built-up Indexes (NDBI) Computation.

Built-up indexes were obtained to determine the relationship between the LST and NDBI development procedure based on the SWIR band 6 and NIR band 5 used as data makeup and modified to NDBI analysis [15]

NDBI = (SWIR Band (6) - NIR Band (5))/(SWIR Band (6) + NIR Band (5)) (7)

Obtain NDBI raster images representing the study area. NDBI values typically range from -1 to 1, with higher values indicating built-up areas such as urban infrastructure. The clustering process is completed by visually examining the clusters on the image to interpret and assign meaningful class labels [16]. High NDBI clusters were used to represent built-up areas; lower NDBI clusters correspond to non-built-up land cover types such as vegetation or bare soil [16].

F. Point-based NDVI, NDBI, and LST relationship analysis

The study conducted on Pearson correlation assesses the significant difference between the selected Land Use and Land Cover values and LST values each year in the site [10].

The spatial distribution around the map was identified, and data from the LULC and LST were collected, developing 2000 sample points [15]. The selected area's vegetation, built-up, and temperature data were analyzed for variation using IBM SPSS software version 25.

G. Analyze spatial and Temporal variation in Climate data

Temporal data was collected from NASA data sets to analyze the variation between spatial and temporal data. Vegetation impact intensity was analyzed by comparing temporal and spatial temperature data collected from the study site [10]. The relationship between temperature, humidity, and precipitation temporal data was determined. Descriptive statistics were performed to determine the spatial and temporal data variance and standard deviation from 2009 to 2024 using IBM SPSS (Version 25) software [17].

IV. Results and Discussion

A. Land Surface Temperature (LST) Analysis

The analysis of the LST reveals a significant decreasing trend in the Muthurajwela area, as shown in Figure 2. Mean values reveal a significant decline from 24.22°C in 2019 to 18.40°C in 2024. Based on the standard deviation from 2014 (2.500) to 2024 (2.577) and median values in 2014 (23.86°C) to 2024 (18.16°C), a decreasing trend of LST was indicated. Range values show a noticeable shift in concentration trend from 2019 (9.31) to 2024 (9.73). LST values show a decreasing trend due to the vegetation cover and enhancement of built-up indexes. The range shows narrowing, and both minimum and maximum values show a rapidly declining tendency. Observations show a significant change in land surface temperature, reflecting the impact of climate change and land use pattern change.

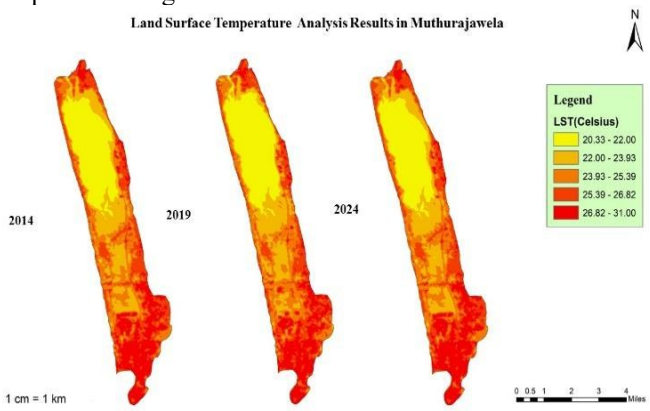


Fig 2-Land Surface Temperature Analysis 2014–2024 in Muthurajwela

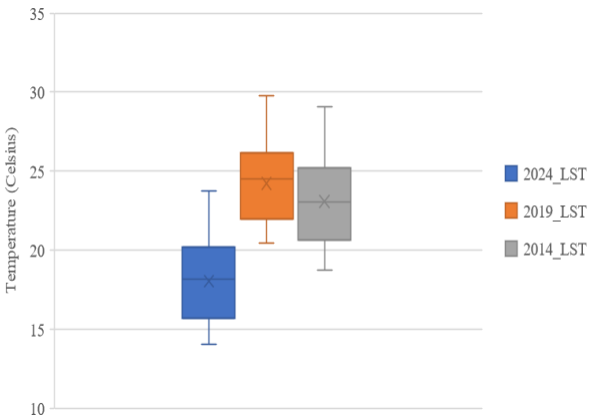


Fig 3- Descriptive Statics of LST Values

B. Vegetation Indexes (NDVI) Computation

The analysis of NDVI mean values reveals significant vegetation loss and stable conditions in the trend from 2009 (0.1162) to 2024 (0.1263) period. A positive trend of decreasing vegetation cover was observed based on the standard deviation in 2009 (0.0063) to 2024 (0.0041) and median values. By 2014, there was a noticeable shift in the NDVI values. Some areas that previously exhibited high NDVI values have decreased, indicating a loss of vegetation. The range of the vegetation cover distribution became less in 2009 (1.096) to 2024 (0.663). The 2019 NDVI map shows

further changes, with a more pronounced reduction in vegetation cover in certain regions. The areas with low NDVI values expanded, suggesting ongoing degradation of the ecosystem. Mode values frequently decrease, indicating the central tendency of the vegetation cover health is commonly low. Based on the minimum and maximum values of the vegetation cover, health consistently decreased over time. The sum of the vegetation cover shows the vegetation cover scattered around. It indicates a significant loss of vegetation cover, which can result in a decline in biodiversity and other ecosystem services offered by the Muthurajawela wetland.

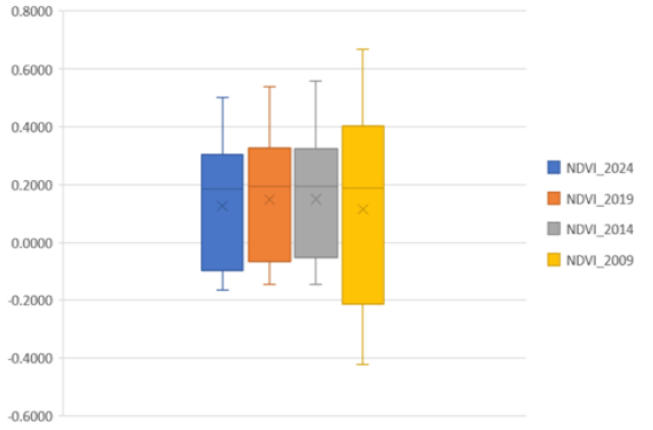


Fig 4-Descriptive statics of NDVI values

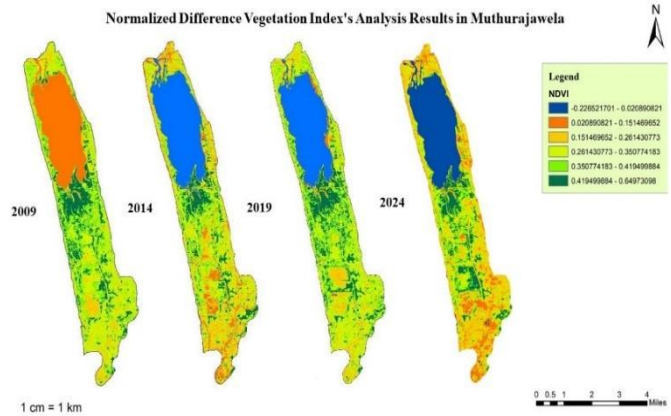


Fig 5-Normalized Difference Vegetation Indexes Analysis in 2009–2024 in Muthurajwela

C. *Normalized Different Built-up Indexes (NDBI) Computation*

Based on Table 05, trend analysis of the mean NDBI values from 2014 (-0.09189) to 2024 (-0.0678) in the Muthurajawela Division in grown condition. Also, the standard deviation indicates a growth of built-up areas from 2014 (0.0016) to 2019 (0.00176) period, but 2024 (0.0017) shows a slight decrease in the initial build-up area, slightly declining or stabilizing. The range of the analysis also shows a less spread condition and slightly increased in 2014 (0.4771) to 2024 (0.0741) in condition. Also, the spread range is higher and the same, followed by a stabilization or slight increase by 2024.

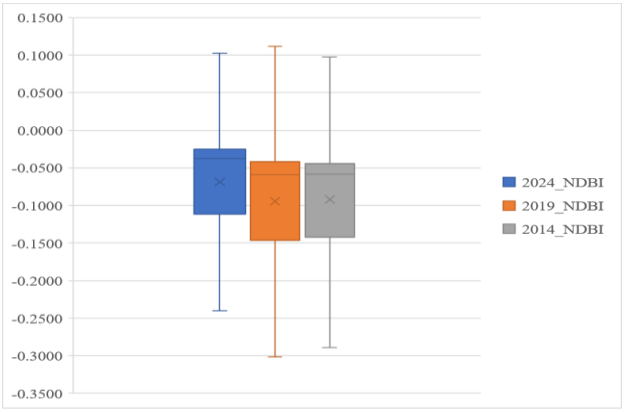


Fig 6-Descriptive statistics of NDBI values

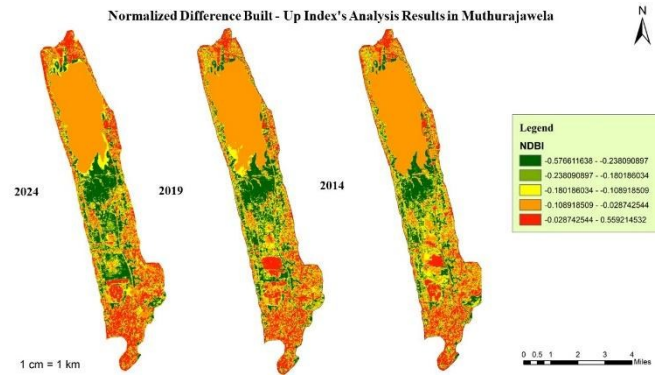


Fig 7-Normalized Difference Built-Up Indexes Analysis in 2009–2024 in Muthurajwela

D. *Point-based NDVI, NDBI, and LST relationship analysis*

The Pearson correlation between the LST and NDVI shows a weak negative relationship from 2014 to 2024. Higher land surface temperature is associated with lower NDVI, implying that vegetation health declines with higher temperature values. The correlation between the LST and NDBI values shows a weak positive trend for relationship analysis in the 2014 to 2024 period. The higher LST value linked to the higher build-up area indicates the slight increase in temperature and urbanization in the Muthurajawela wetland through the past decade.

Table 1- Pearson Correlation Analysis Results

		LST	NDBI	NDVI
Pearson Correlation	LST_ 2024	0.100	-0.161
	LST_ 2019	0.162	-0.162
	LST_ 2014	0.201	-0.196

E. *Analyze Spatial and Temporal Variation in Climate data.*

1. *Trend Analysis Results*

The analysis of temperature, relative humidity, and annual rainfall data from 2009 to 2023 indicates significant changes in the climate of the Muthurajawela wetland area. Average temperature trends (2009-2023) over the 15 years are approximately 26.14°C, with a standard deviation of 1.58°C, indicating relatively stable conditions. The relatively stable

temperature readings suggest a consistent climate, although the peaks indicate potential anomalies linked to specific climatic events or changes in land use. The slight increase in 2023 could be indicative of broader climate change trends.

The maximum recorded temperature is 27.5°C, while the minimum is 25.0°C. Notable peaks in temperature occurred in 2010, 2016, and 2021, observed periods of warmer conditions. The year 2023 shows a slight increase, indicating a potential upward trend, and relative humidity fluctuations show a dynamic climate system. Increased humidity levels are associated with various factors, including changes in vegetation cover, land use, and seasonal weather patterns. The peak in 2023 may reflect changes in precipitation patterns or increased evaporation rates due to higher temperatures. Relative Humidity Trends (2009-2023) in 2 meters around 82.06%, with a standard deviation of 3.64%. The values range from a minimum of 78.4% to a maximum of 86.4%. A peak in relative humidity was observed in 2023 at 85.7%, while the lowest point was around 78.4% in 2009. The data shows fluctuations, with notable increases in humidity during certain years, particularly in 2015 and 2023.

The annual rainfall distribution highlights significant variability, with peaks suggesting periods of increased precipitation. The increase in rainfall in 2023 may indicate a shift in seasonal patterns or the influence of climate variability, with implications for water resources and agriculture. Annual rainfall distribution (2009-2023) indicates variability, with total precipitation ranging from approximately 1,600 mm to 3,000 mm. The average annual rainfall was found as 2,242.45 mm. The rainfall distribution peaks in 2010, 2016, and 2021, with a notable increase in 2023, suggesting a potential shift in precipitation patterns. The relationship between temperature, humidity, and rainfall is crucial for understanding local climate dynamics. Higher temperatures increase evaporation, potentially raising humidity levels in the Muthurajawela wetland area. The distribution of the rainfall patterns directly impacts both temperature and humidity.

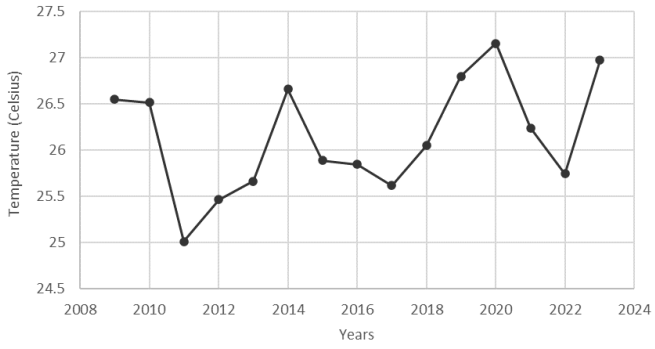


Fig 8-Temperature Distribution 2009–2023.

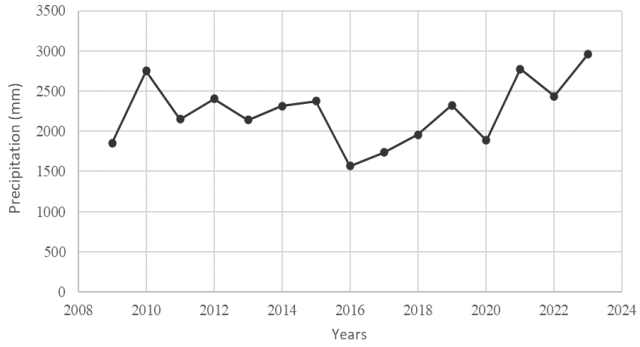


Fig 9-Annual Rainfall Distribution 2009 – 2023.

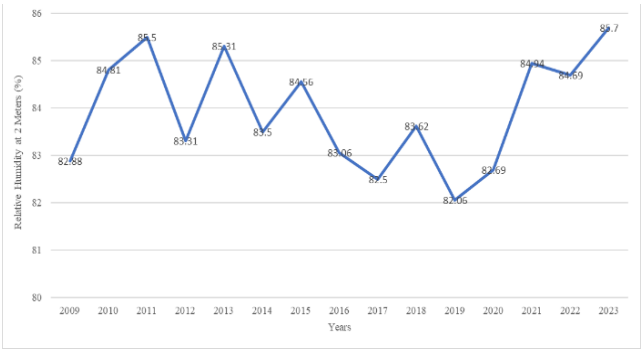


Fig 10-Annual Relative Humidity 2 m (%) 2009 - 2023.

The analysis of vegetation cover pattern changes in the Muthurajawela area from 2009 to 2024 reveals significant insights when considering the climatic statistics. The annual relative humidity at 2 meters has a mean of 83.94%, indicating consistently high humidity levels that support lush vegetation growth. The low range of 3.64 suggests minimal fluctuations, contributing to stable vegetation. cover. Precipitation data shows a mean of 2242.45 mm, highlighting substantial rainfall essential for sustaining vegetation. The considerable range of 1,602.48 mm indicates variability that impacts vegetation patterns, particularly during dry spells or extreme weather events. Temperature readings with a mean of 25.17 °C and a low standard deviation of 1.38 suggest a stable environment conducive to vegetation growth.

2. *Temporal climate database Relationship analysis*

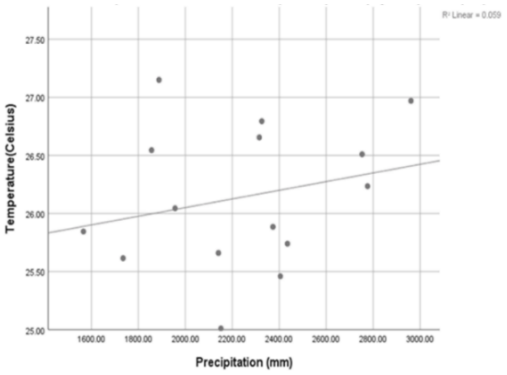


Figure 11- Relationship between temperature and precipitation

The trend of the fitted line (regression line) shows a slight upward slope as precipitation increases; temperature also tends to increase. The R^2 value is 0.053, suggesting that only about 5.3% of the variance in Temperature is explained by changes in precipitation. This indicates a weak relationship between the two variables. The scatter plot shows a weak positive correlation between temperature and precipitation, as indicated by the upward trend line and low R^2 value.

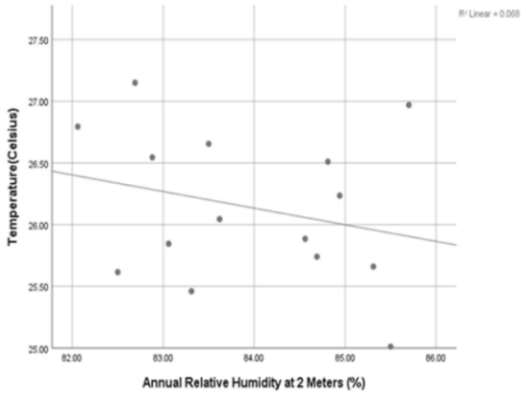


Fig 12- Relationship between temperature and relative humidity

The scatter plot contains several data points scattered across the graph, indicating individual observations of temperature and annual relative humidity increases. Temperature tends to decrease. The R^2 value is 0.092, indicating that only about 9.2% of the temperature variance is caused by annual relative humidity changes. This suggests a weak relationship between the two variables. The scatter plot indicates a weak negative correlation between temperature and annual relative humidity, as evidenced by the downward trend line and low R^2 value.

F. Temporal climate data correlation analysis results

The correlation matrix presented in Table 2 reveals important relationships among annual relative humidity, precipitation, and temperature. The analysis reveals a moderate positive correlation (r = 0.624) between annual relative humidity at 2m (%) and precipitation, indicating that as precipitation increases, relative humidity tends to rise as well. Conversely, a weak negative correlation (r = -0.261) between annual relative humidity and temperature suggests that higher temperatures are generally associated with a slight decrease in relative humidity. Additionally, the correlation between precipitation and temperature is weakly positive (r = 0.243), meaning that precipitation shows a modest upward trend as temperature increases. These correlations are statistically significant at the 0.05 level (2-tailed). These findings highlight the complex but consistent relationships among temperature, relative humidity, and precipitation, with temperature exerting a modest influence on both humidity and precipitation patterns.

Table 2- Pearson Correlation analysis results in climate factors

	Annual Relative Humidity (%)	Precipitation (mm)	Temperature (°C)
Annual relative humidity (%)	1	0.624	-0.261
Precipitation (mm)	0.624	1	0.243
Temperature (°C)	-0.261	0.243	1

Relative humidity, temperature, and precipitation show a clear trend between vegetation cover because the health of vegetation cover reduces the influence of climate pattern change. Because of that, the wetland environment was critically impacted during the period based on the temporal analysis [18]. Under these circumstances, environmental conditions rapidly change during the period, and vegetation cover loss directly impacts the native species in the habitat [19]. Feeding grounds and breeding grounds change stress environmental conditions threatened species' survivability of the area [20]. A graphic of study maps provides insight for determining and implementing strategies for the suitability of different sites around the Muthurajwela wetland conservation process [6].

Effective conservation of vegetation cover in the Muthurajawela wetland requires a multi-faceted approach. These include promoting the sustainable use of the wetland, halting encroachment, and prioritizing restoration and rehabilitation efforts [17]. Restoration of the wetland using native plant species is essential to preserving local biodiversity and ensuring ecosystem resilience [18]. Raising community awareness about the ecological importance of wetlands and involving local communities in decision-making processes related to urban planning and wetland management are crucial for long-term conservation. Additionally, enhancing coordination among stakeholders can strengthen conservation efforts [20]. Promoting sustainable economic activities, such as ecotourism, can further reduce the pressure on the wetland by providing alternative livelihoods for local communities.

V. CONCLUSION

The study revealed that urbanization significantly affects the vegetation dynamics and land surface temperature (LST) in the Muthurajawela wetland. Key findings include a strong correlation between increasing built-up areas (NDBI) and rising surface temperatures, while areas with vegetation loss (NDVI) demonstrated higher LST values. The analysis of 2000 sample points showed that urbanized regions contributed more to temperature increase and vegetation degradation. Using IBM SPSS and ArcGIS, the study identified that the decline in vegetation cover directly corresponds to rising land surface temperatures, further indicating the environmental stress caused by urban expansion. The findings emphasize the need for sustainable urban planning and wetland conservation strategies to mitigate the adverse effects of urbanization on this critical ecosystem. Future research should expand on these findings, focusing on broader regional applications to develop long-term wetland preservation and climate resilience solutions.

REFERENCES

[1] A. L. de Castro, M. L. Duarte, H. Ewbank, and R. W. Lourenço, "Use of synthetic aperture radar data for the determination of normalized difference vegetation index and normalized difference water index," *J. Appl. Remote Sens.*, vol. 18, no. 1, p. 014516, Feb. 2024, doi: 10.1117/1.JRS.18.014516.

[2] D. Athukorala, R. C. Estoque, Y. Murayama, and B. Matsushita, "Impacts of urbanization on the Muthurajawela Marsh and Negombo Lagoon, Sri Lanka: Implications for landscape planning towards a sustainable urban wetland ecosystem," *Remote Sens.*, vol. 13, no. 2, p. 316, 2021.

[3] G. Chen *et al.*, "Global projections of future urban land expansion under shared socioeconomic pathways," *Nat. Commun.*, vol. 11, no. 1, p. 537, Jan. 2020, doi: 10.1038/s41467-020-14386-x.

[4] M. Ranagalage, R. C. Estoque, and Y. Murayama, "An Urban Heat Island Study of the Colombo Metropolitan Area, Sri Lanka, Based on Landsat Data (1997–2017)," *ISPRS Int. J. Geo-Inf.*, vol. 6, no. 7, Art. no. 7, Jul. 2017, doi: 10.3390/ijgi6070189.

[5] Central Environmental Authority, Euroconsult. Conservation Master Plan, Muthurajawela Marsh and Negombo Lagoon; Gunaratne offset Ltd.: Colombo, Sri Lanka, 1994

[6] H. D. Dahanayake, D. Dahanayaka, P. Hudson, and D. Wickramasinghe, "Analyzing land use changes and wetland dynamics: Muthurajawela urban wetland and its surroundings, Sri Lanka," *J. Degraded Min. Lands Manag.*, vol. 11, no. 4, pp. 6441–6452, 2024.

[7] X. Yu, X. Guo, and Z. Wu, "Land Surface Temperature Retrieval from Landsat 8 TIRS—Comparison between Radiative Transfer Equation-Based Method, Split Window Algorithm and Single Channel Method," *Remote Sens.*, vol. 6, no. 10, Art. no. 10, Oct. 2014, doi: 10.3390/rs6109829.

[8] W. Han *et al.*, "Spatiotemporal Variation of NDVI in Anhui Province from 2001 to 2019 and Its Response to Climatic Factors," *Forests*, vol. 13, no. 10, p. 1643, 2022.

[9] Y. A. Singgalen, "Implementation of Spatio-Temporal Analysis for Land Use Management and Urban Planning in North Halmahera Regency," *KLIK Kaji. Ilm. Inform. Dan Komput.*, vol. 4, no. 2, pp. 913–925, 2023.

[10] X. Ge, D. Mauree, R. Castello, and J.-L. Scartezzini, "Spatio-temporal relationship between land cover and land surface temperature in urban areas: a case study in Geneva and Paris," *ISPRS Int. J. Geo-Inf.*, vol. 9, no. 10, p. 593, 2020.

[11] U. Avdan and G. Jovanovska, "Algorithm for automated mapping of land surface temperature using LANDSAT 8 satellite data," *J. Sens.*, vol. 2016, pp. 1–8, 2016.

[12] A. Karimi, P. Pahlavani, and B. Bigdeli, "Land use analysis on land surface temperature in urban areas using a geographically weighted regression and Landsat 8 imagery, a case study: Tehran, Iran," *Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci.*, vol. 42, pp. 117–122, 2017.

[13] S. Guha, H. Govil, N. Gill, and A. Dey, "Analytical study on the relationship between land surface temperature and land use/land cover indices," *Ann. GIS*, vol. 26, no. 2, pp. 201–216, Apr. 2020, doi: 10.1080/19475683.2020.1754291.

[14] K. A. Okoduwa, C. F. Amaechi, and A. A. Enuneku, "Soil Adjusted Vegetation Index, Normalize Difference Buildup Index, and Land Surface Temperature between 1987 and 2023 in Abuja Municipal Area Council, Nigeria," *J. Appl. Sci. Environ. Manag.*, vol. 28, no. 3, pp. 665–674, 2024.

[15] W. Ullah *et al.*, "Analysis of the relationship among land surface temperature (LST), land use land cover (LULC), and normalized difference vegetation index (NDVI) with topographic elements in the lower Himalayan region," *Heliyon*, vol. 9, no. 2, p. e13322, Feb. 2023, doi: 10.1016/j.heliyon. 2023.e13322.

[16] C. A. Popescu, A. Horablaga, M. V. Herbei, R. Bertici, D. Dicu, and F. Sala, "Supervised and unsupervised classification based on remote sensing for study of an area," in *AIP Conference Proceedings*, AIP Publishing, 2024. Accessed: Jul. 16, 2024. [Online]. Available: https://pubs.aip.org/aip/acp/article-abstract/3094/1/420005/3297164

[17] M. Ranagalage *et al.*, "Spatiotemporal variation of urban heat islands for implementing nature-based solutions: A case study of Kurunegala, Sri Lanka," *ISPRS Int. J. Geo-Inf.*, vol. 9, no. 7, p. 461, 2020.

[18] S. Apostolaki, "Nature-Based Solutions for Sustainable Stormwater Management as Means to Increase Resilience to Climate Change, Promote Circularity and Improve City Aesthetics," in *Nature-based Solutions for Circular Management of Urban Water*, A. Stefanakis, H. V. Oral, C. Calheiros, and P. Carvalho, Eds., in Circular Economy and Sustainability. , Cham: Springer International Publishing, 2024, pp. 315–331. doi: 10.1007/978-3-031-50725-0_18.

[19] A. S. D. M. I. Ahmed and R. A. P. Roy, "Responses of NDVI anomaly to SPI for vegetation over the years 2000-2019: A case Study of Raichur district," 2021, Accessed: May 26, 2024. [Online]. Available: https://www.researchgate.net/profile/Rizwan-Ahmad-13/publication/354354800_Responses_of_NDVI_anomaly_to_SPI_for_vegetation_over_the_years_2000-2019_A_case_Study_of_Raichur_district/links/613a3fefee29a068c7152203/Responses-of-NDVI-anomaly-to-SPI-for-vegetation-over-the-years-2000-2019-A-case-Study-of-Raichur-district.pdf

[20] M. Gunathilaka and W. T. S. Harshana, "Evaluation of urban heat island (UHI) spatial change in freshwater lakes with hot spot analysis (GI statistics)," *Int. J. Environ. Eng. Educ.*, vol. 3, no. 2, pp. 48–58, 2021

Assessing Greenhouse Gas Emissions from Integrated Rice-crop Systems in the Dry Zone of Sri Lanka: A Case Study in Ampara District

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***Abstract*— Rice is the staple food in Sri Lanka and requires substantial agronomic inputs to achieve optimal yields necessary to meet the nation's growing demand. However, paddy cultivation is a major contributor to environmental degradation, accounting for approximately 52% of the agricultural sector's greenhouse gas (GHG) emissions. This study aimed to quantify the global warming potential (GWP) of a paddy intercropping system in the Ampara district of Sri Lanka. The study was conducted on a 4.825-hectare plot, comprising 4.425 hectares under paddy, 0.2 hectares under turmeric, and 0.2 hectares under cowpea. The total GHG emissions from paddy cultivation were calculated to be 19,136.72 kg CO_2 eq/ha annually, with nitrous oxide (N_2O) emissions from soil leaching being identified as the primary source. Paddy, turmeric, and cowpea contributed 88.43, 10.46, and 1.11%, respectively, to the total GHG emissions from the intercropping system. It was further observed that incorporating cowpea in 10% of the cultivated area could reduce total GHG emissions from paddy by 6.76%. Additionally, the adoption of sustainable practices, including the application of composted rice straw, biochar, and deep placement of urea fertilizers, presents significant potential for mitigating the GWP of paddy-based cropping systems. These results underscore the necessity of integrating climate-smart agricultural techniques to reduce the carbon footprint of rice production while maintaining sustainable yield levels critical for national food security.**

Keywords—paddy cultivation, integrated cropping system, greenhouse gas emissions, global warming potential

I. INTRODUCTION

Agricultural activities were responsible for 12% of global net anthropogenic emissions, equating to 6.2±1.4 $GtCO_2eq$ per year, between 2007 and 2016 [1]. It is responsible for the majority of the world's non-carbon dioxide (non-CO_2) emissions, producing 84% of nitrous oxide (N_2O) and 47% of methane (CH_4), and accounts for roughly 10%–17% of all human-caused greenhouse gas (GHG) emissions [2]. Paddy rice accounts for 9-11% of greenhouse gas emissions from agriculture [3][4]. Rice cultivation is crucial for ensuring global food security, as it is a primary food source for more than half of the global population [5]. In Sri Lanka, rice, cultivated during two monsoon seasons, is the dominant crop, covering over 12% of the nation's [1]. Rice field methane (CH_4) emissions contribute to 52% of the country's agricultural greenhouse gas emissions [1]. Sri Lanka has pledged to achieve net-zero emissions by 2060 and reduce national GHG emissions by 14.5% between 2020 and 2030 [1].

High-yield rice cultivars deplete soil fertility more quickly than traditional varieties [6]. For every ton of paddy produced, rice crops absorb 20 kg of nitrogen (N), 11 kg of phosphorus (P_2O_5), and 30 kg of potassium (K_2O) from the soil [6]. Farmers often apply large quantities of chemical fertilizers to address the loss of these nutrients, particularly targeting the replenishment of key macro-elements [6]. Rice is a semi-aquatic plant typically submerged completely in water [7]. This creates an anaerobic environment, which is used by methanogens and denitrifiers to break down organic materials and lower nitrate (NO_3^-), respectively [7].

GHG emissions in paddy cultivation are divided into direct and indirect categories. Direct emissions include CO_2 from respiration, N_2O from nitrogen application, and CH_4 from paddy fields [8]. Methane, generated by methanogenic bacteria in anaerobic conditions, accounts for 10–13% of global CH_4 emissions, making rice cultivation a major contributor to global warming [6]. The primary source of N_2O emissions is microbial nitrogen transformations in the soil [8]. While paddy fields emit less CO_2 than CH_4 and N_2O, these emissions result from both biotic and abiotic processes [8]. Indirect emissions in rice-cropping systems arise from activities such as the use of fertilizer, electricity and diesel oil, fuel combustion, and irrigation [8].

Mitigating greenhouse gas emissions through agriculture is one of the most economical and socially acceptable ways to meet these national goals [1].

To build climate resilience, environmentally benign rice-based farming systems must be adopted in response to the effects of climate change. Crop rotation throughout the year helps maintain stable food production, which supports food security, enhances nutritional diversity, and increases revenue while reducing risks related to market changes, diseases, pests, and climate change [6]. Including pulses in crop rotation can also improve soil fertility and water-use efficiency [6]. Therefore, developing cultivation practices

and exploring crop diversification are crucial for sustaining natural resources and soil health, particularly for long-term rice production [6].

Integrating legumes into cropping systems as cash crops, cover crops, or intercrops is an essential strategy for reducing the need for nitrogen fertilizers within individual crop cycles and across rotational systems [9][10]. According to numerous studies conducted worldwide, utilizing integrated agronomical methods can reduce the carbon emissions linked to crop inputs by 25 to 50%, enhance system productivity by 15 to 50%, and decrease cereal crops' carbon footprint (CF) by 25 to 35 [10]. When designing a diverse cropping system, it is important to assess the total GHG emissions (CO_2, N_2O, and CH4) and the carbon footprint of each individual crop [10]. Crops that require minimal farm inputs and generate a high yield of crop residues, which can be incorporated into the soil to enhance carbon content, are crucial for lowering the overall carbon footprint of the system [10]. So, this study aimed to estimate the carbon emissions of an integrated crop system in a dry zone of Sri Lanka and identify the most suitable crop for integration with paddy cultivation.

II.METHODOLOGY

Study area:

The selected study area is a paddy field located in Kothmale village (K.C. Colony), within the Uhana region of the Ampara district. This site was chosen due to its relevance in reflecting the typical agronomic practices prevalent in the region, making it suitable for an in-depth analysis of greenhouse gas emissions associated with rice cultivation. The selection of this site allows for the generation of findings that apply to similar agricultural systems in the Ampara district and beyond. As illustrated in Fig 1, this location provides a relevant context for evaluating the environmental impacts of integrated cropping systems in paddy fields.

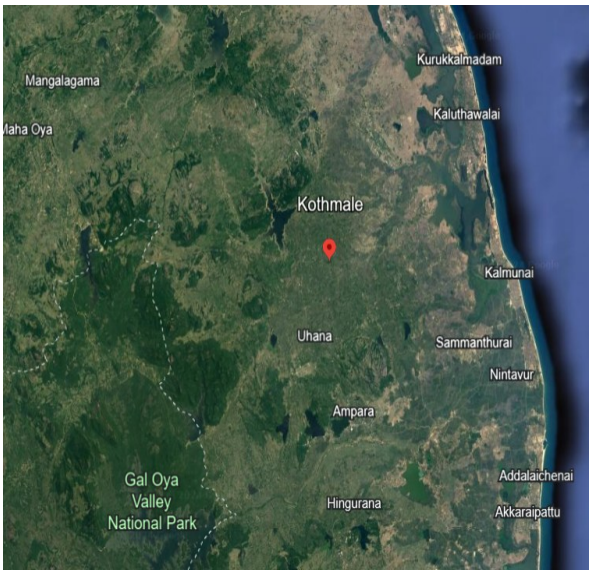


Fig 1- Areal view of the study area (Google Earth)

Table 1: Profile of the selected land

Data	Rice cultivation	Peas cultivation	Turmeric cultivation
Land area (ha)	4.452 ha	0.2 ha	0.2ha
Length of planting (days)	120 days(two seasons per year)	75 days(two times per year)	1 year
Productivity (kg / ha)	5700 kg / ha	1200kg / ha	17500kg / ha
Water feeding (m^3)	2,613.600	12	54.45

Data collection:

In this study, data for GHG emissions such as area cultivation, productivity, fertilizer application, and diesel consumption were collected from the farmers.

Calculation approach:

GHG emissions calculation in rice production involves several key steps, each focusing on different sources of emissions.

.1. Emission from fossil fuel utilization (EM):

GHG emissions from the fossil fuel burning in tractors and harvesters were estimated based on the equations [11].

Emissions from diesel fuel utilization = Ai x EF_1 (1)

Were.

A_i represents the quantity of diesel fuel (in liters).

EF is the diesel fuel combustion emission factor, expressed in kg CO_2 equivalents.

2. Direct N_2O Emissions from Managed Soil

$$\text{Direct } N_2O = [F_{SN} + F_{CR} + F_{COMPST} + F_{SOM}] * EF_2 * {}^{44}/_{2} \quad (2)$$

where,

F_{SN} stands for the annual amount of N in urea application (kg N y^{-1}),

F_{CR} stands for the annual amount of N in crop residue application (kg N y^{-1}),

$F_{COMPOST}$ stands for the annual amount of N in compost fertilizer application (kg N y^{-1}), and

F_{SOM} stands for the annual amount of N released in soil organic matter mineralization (kg N y^{-1})

4. Indirect N_2O emission

Indirect N_2O emissions

$$\text{From volatilization} = F_{SN} * Frac_{vol} + F_{CR} + F_{COMPST} + Frac_{vol} * EF_3 * {}^{44}/_{28} \quad (3)$$

From leaching$=[F_{_SN}+F_{CR}+F_{COMPST}+F_{SOM}]*Fract_{Leach}*EF_3*44/2$ (4)

4. CH_4 emission

EF = (EFc x $SF_{W\,x}$ SFp × SFo) (5)

Where;

EF -adjusted daily emissions factor for a particular harvested area
EFc- the baseline emissions factor for continuously flooded fields without organic amendments
SFw -scaling factor to account for the differences in water regime during the cultivation period
SFp - scaling factor to account for the differences in water regime in the season before the cultivation period
SF_O scaling factor that accounts for differences in both type and amount of organic amendment applied source

$$SFo = (1 + \Sigma_i ROA_i \times CFOA_i)^{0.59} \quad (6)$$

Where ROAi is the application rate of organic amendment i in dry weight for straw and fresh weight for others in tons ha^{-1}, and CFOAi is the conversion factor for organic amendment i in terms of its relative effect with respect to straw applied shortly before cultivation.

5) CO_2 emission from urea application
Urea, in the presence of urease enzymes and water, is broken down into NH_4^+, OH^-, and HCO_3^- [12]. The bicarbonate formed in this process eventually transforms into CO_2 and water, with most of the carbon in urea being emitted as CO_2 [12]. Since urea fertilizer contains 12 grams of carbon for every 28 grams of nitrogen, this translates to a global warming potential (GWP) of 1.6 kg of CO_2 per kilogram of urea-N applied [12].

Annual CO_2 emissions from urea = Annual urea amount applied × EF (7)

Table 2- Emission factors used for estimating GHG emission

Emission factor	Value	Source of reference
EF1	2.6705	[13]
EF2	0.01	[14]
FracVOL	0.15	[1]
$Fract_{Leach}$	0.24	[1]
EFc	0.85	[1]
SFw	0.55	[1]
SFp	1	[1]

III. Results And Discussion

The GHG emissions were quantified for paddy cultivation and the associated intercrops, cowpea and turmeric, as detailed in Table 4. Annual total GHG emission from the paddy intercropping system was estimated as 27434.81 CO_2 eq/kg. Leaching of N_2O from the soil was identified as the major source of GHG emissions. Annual GHG emissions from paddy, cowpea, and turmeric are estimated as 24644.97 CO_2 eq/kg, 71.60 CO_2 eq/kg, and 2718.24 CO_2 eq/kg, respectively (Fig 2). These results indicate that paddy cultivation is the dominant contributor to GHG emissions within the system, primarily due to N_2O emissions, while the intercrops contribute comparatively lower amounts. This highlights the importance of exploring crop diversification and sustainable management practices to reduce the environmental impact of paddy cultivation.

Table No 3: Estimation of GHG emissions from the crops

Crop	Source	CO_2 eq / kg
Paddy	Urea fertilizer (CO_2 emission)	660.00
	CH_4 Emissions	3891.29
	Nitrogen fertilizer emissions (N_2O Emissions)-Urea	4168.63
	Indirect emissions -N_2O volatilization -urea+crop residue	5800.53
	Leaching N_20 -urea+crop residue	7827.89
	Diesel oil emissions (CO_2+NO_2+CH_4)-Machinery use	2296.63
	Total	24644.97
Cowpea	CH_4 Emissions	17.53
	Diesel oil emissions (CO_2+NO_2+CH_4)-Machinery use	53.41
	Indirect emissions -N_2O volatilization -urea+crop residue	0.26
	Leaching N_20 -urea+crop residue	0.33
	Nitrogen fertilizer emissions (N_2O Emissions)-Albert solution	0.07
	Total	71.60
Turmeric	Urea fertilizer (CO_2 emission)	78.00
	Diesel oil emissions (CO_2+NO_2+CH_4)-Machinery use	26.71
	CH4 Emissions	383.25
	Indirect emissions -N_2O volatilization -urea+crop residue	319.19
	Leaching N_20 -urea+crop residue	534.18
	Nitrogen fertilizer emissions (N2O Emissions)-Urea and animal manure	1376.91
	Total	2718.24

CO_2, CH_4, and N_2O account for 15.5%, 21.5%, and 63.0% of total GHG emissions of the intercropping system (Fig 2).

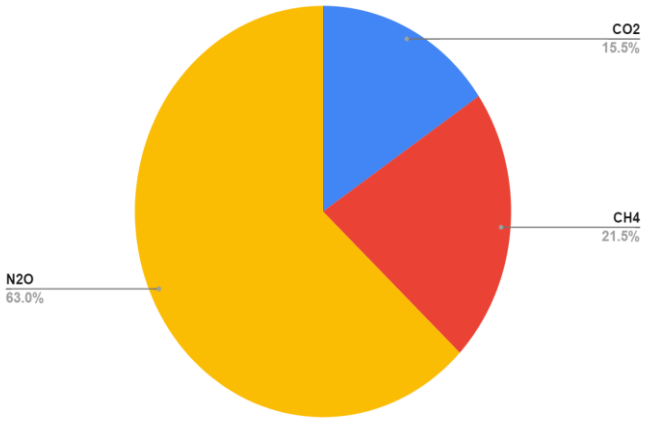
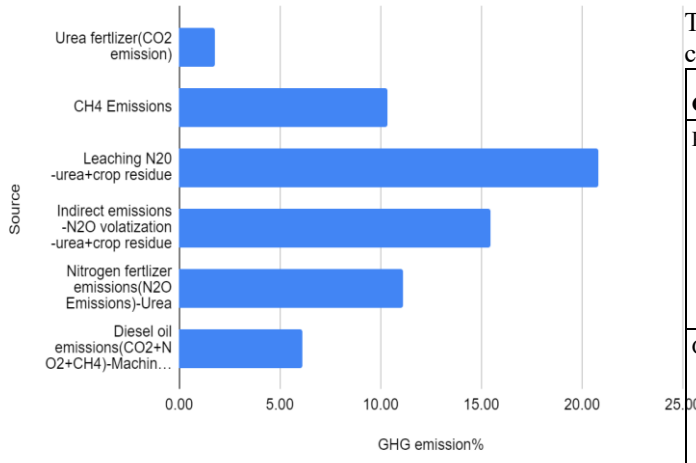


Fig 2- Contribution of different GHG emissions to intercropping system

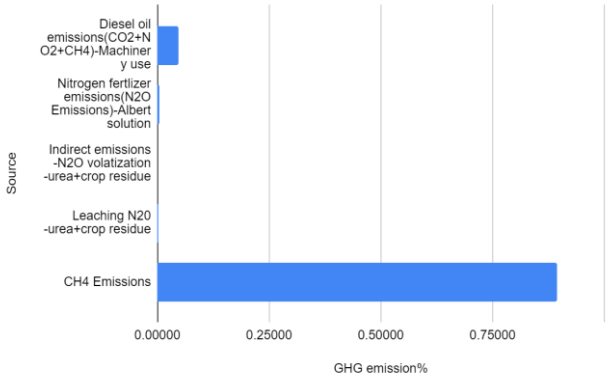
The application of pesticides and herbicides at the study site is conducted manually rather than mechanized. This practice results in negligible GHG emissions associated with the use of these substances, as the manual application does not

involve fuel consumption or emissions typically associated with machinery. The paddy cultivation site under the study utilizes a gravity-driven irrigation system. This method of water application does not require energy-intensive pumps or machinery, thereby avoiding GHG emissions that are commonly generated by other irrigation systems. The reliance on natural gravity for water distribution contributes to the site's overall low GHG emission profile.

N_2O was the major GHG emitted from paddy cultivation due to the extensive use of nitrogen fertilizers such as urea, while CO_2 emerged as the least contributor (fig 3). Direct and indirect N_2O emissions account for 33.92% and 66.08% of total N_2O emissions, respectively. Fertilizer-related greenhouse gas emissions in rice-based cropping systems account for 17.54-80.39% of indirect emissions [8]. Fertilizer application influences soil pH, temperature, and bacterial content, indirectly affecting gas emissions [8]. Applying nitrogen (N) fertilizer close to the active root uptake zone can reduce surface nitrogen loss and improve plant nitrogen use efficiency, lowering N_2O emissions [12]. Additionally, splitting nitrogen applications across different crop growth stages can further improve nitrogen use efficiency and minimize nitrogen losses [12].



(a)



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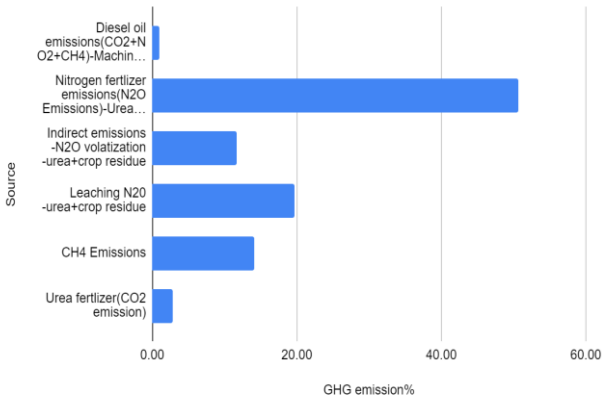


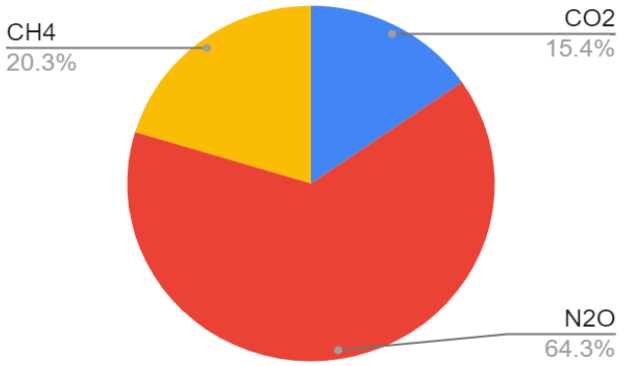
Table 4- GHG emission from paddy, cowpea and turmeric cultivation

Crop	GHG category	Amount (CO_2 eq / kg)
Paddy	CO_2	2939.17
	N_2O	17813.32
	CH4	3891.978
	Total	24644.468
Cowpea	CO_2	53.00
	N_2O	0.66
	CH_4	3.51
	Total	57.17
Turmeric	CO_2	166.502
	N_2O	1377.67
	CH_4	186.72
		1730.892

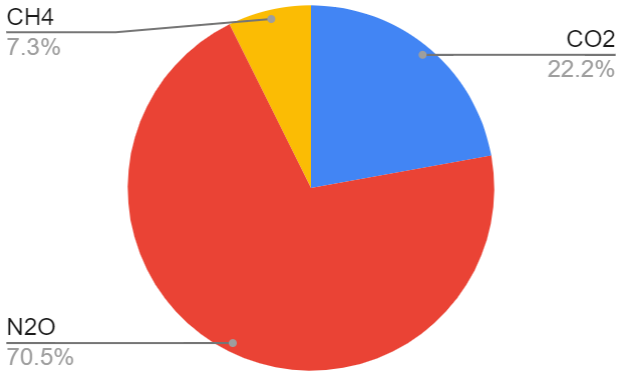
CH_4 was found as the second-largest emitter in paddy cultivation in this study as shown in the fig 4. As a cause of climate change, methane is only second to carbon dioxide as its global warming potential is 23 times greater than carbon dioxide on a mass balance basis. Therefore, reducing methane emission can reduce the total global warming potential of rice crop systems. The main factors influencing rice field CH_4 emissions are irrigation scheduling, duration, and quantity of organic carbon inputs [1].

(c)

Fig 3- Total GHG emission of paddy(a), cowpea(b) and turmeric(c) cultivatiio



(a)



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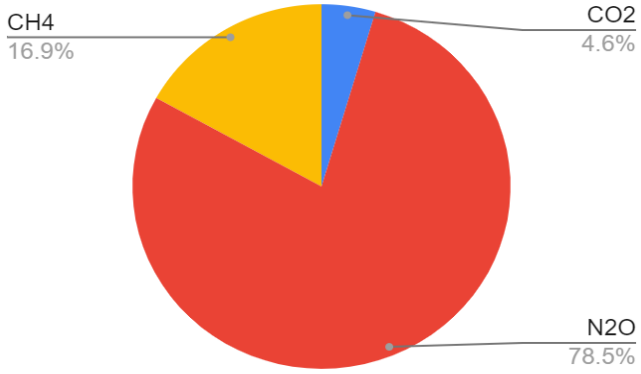

(c)

Fig4- GHG emission distribution from paddy(a), turmeric(b) and cowpea(c) cultivation.

Furthermore, a statistical analysis of an extensive field-measurement data set revealed that, in comparison to continuous flooding, a single midseason aeration can decrease average seasonal CH_4 emissions by 40%, while multiple aerations can reduce it by 48% [15].

Aerobically composted straw has been proposed as a potential organic material for reducing CH_4 emissions from rice paddies due to its more stabilized carbon content [16]. CH_4 generated in the soil undergoes dissolved diffusion across water–air and soil–water interfaces, can be lost through ebullition, is transported to plant roots via diffusion, converted into gaseous CH_4 within the aerenchyma and cortex, and is ultimately released into the atmosphere through micropores in the plant [8]. Therefore, growing rice cultivars with underdeveloped aerenchymal systems would be a mitigation strategy to lower methane emissions to the atmosphere [5] [17]. Since drought-resistant rice cultivars can drastically cut down on irrigation water use, they may help with attempts to mitigate the effects of climate change and adapt to them [8]. In comparison with the typical variety cultivated under flooded and wet intermittent irrigation, the drought-resistant rice lowered CH_4, N_2O, and CO_2 emissions by 21.5, 3.7, and 9.8%, respectively [8]. Studies have found that CH_4 emissions increase with the height of rice plants. Varieties that reach 120 cm in height emit 2.9 times more CH_4 than those that are 90 cm tall. Therefore, shorter rice varieties are more effective in reducing carbon emissions compared to taller ones [7].

High-yielding cultivars also minimize emissions, mostly by altering photosynthetic product allocation to raise the harvest index and lower the carbon source needed for methanogenic bacterial growth [8]. Tillage practices greatly influence soil respiration and the microenvironments both at the surface and subsurface levels, which in turn affect soil organic carbon fixation and carbon emissions [8] [18]. Prolonged use of no-tillage (NT) practices has the potential to enhance soil structure and reduce soil temperature, primarily due to surface residues that reflect incoming radiation and create a barrier between the soil and the atmosphere [18]. In warm, arid regions, NT may serve as a critical strategy for mitigating N_2O emissions, in contrast to conventional tillage practices, which can elevate N_2O emissions through increased decomposition of organic matter and intensified microbial activity [18].

Additionally, straw compost has demonstrated the ability to keep N_2O emissions low [19]. According to a study by Pandey et al., 2014, incorporating biochar derived from rice straw into the soil can reduce global warming potential and CH_4 and N_2O emissions in paddy cultivation under intermittent drying. Applying biochar to agricultural land can lower greenhouse gas emissions while enhancing soil carbon pools, leading to higher-quality crops and significant ecological and environmental advantages [8].

The region adopted the application of irrigation water with multiple drainage periods, so the paddy lands are not covered with water throughout the cultivation period. So, the selected location undergoes a limited period of anerobic condition, leading to comparatively less CH_4 production.

Nitrification inhibitors could serve as a strategy to mitigate N_2O emissions by slowing the oxidation of NH_4^+, thereby reducing the loss of N_2O during nitrification and

denitrification [16]. Applying Dicyandiamide (DCD) with urea can significantly reduce N_2O emissions from paddy

cultivation [16]. Soil reduction can be halted by introducing an electron acceptor, such as SO_4^{2-} or NO_3^-, into the soil. The application of sulfate, particularly through ammonium sulfate, can inhibit CH_4 production by reducing the activity of methanogens by limiting substrate availability in waterlogged soils [16]. In addition, integrated rice and aquatic animal production systems can be adopted to reduce GHG in paddy cultivation [8]. The rice-fish system has a carbon footprint (CF) that is 0.8 times smaller than that of organic rice farming [8].

N_2O was the largest contributor to GHG emissions in turmeric cultivation due to the extensive application of urea fertilizer, rice straws, and animal manure. CO_2 was found to be the least GHG from turmeric cultivation. Direct N_2O and indirect N_2O emissions are responsible for 77.50% and 22.50% of total N_2O emissions, respectively. In cowpea cultivation, CO_2 was found as the major GHG due to the machinery used in the land preparation while N_2O was found as the lowest GHG due to the least use of nitrogen fertilisers. Direct N_2O and indirect N_2O emissions are responsible for 0.16% and 99.84% of total N_2O emissions, respectively

In a comparative analysis of greenhouse gas (GHG) emissions associated with the cultivation of paddy, cowpea, and turmeric on a 0.2-hectare plot, significant differences were observed in their respective carbon footprints. The GHG emissions were found to be as follows: paddy accounted for 864.94 kg CO_2 eq, cowpea 239.23 kg CO_2 eq, and turmeric a substantially higher 2264.64 kg CO_2 eq per kilogram of produce. This data indicates that turmeric cultivation leads to significantly higher GHG emissions compared to both paddy and cowpea. The elevated emissions from turmeric cultivation raise environmental concerns, particularly when grown on a large scale. Given its substantial carbon footprint, large-scale turmeric production is not environmentally advisable. As a mitigation strategy, turmeric should be cultivated as an intercrop alongside major crops, helping to optimize land use and reduce overall emissions associated with monocropping practices.

In the intercropping system, which includes paddy, cowpea, and turmeric cultivation, the distribution of GHG emissions was as follows: paddy cultivation accounted for 88.43% of the total GHG emissions, cowpea contributed 1.11%, and turmeric made up 10.46%. Paddy cultivation occupies 90% of the land, while cowpea and turmeric each cover 5% of the land. If 10% of the land currently used for paddy cultivation were instead cultivated with cowpea, it could reduce GHG emissions from paddy fields by approximately 6.76%. This reduction strategy is particularly relevant in the Ampara district, where farmers have adopted intercropping practices in response to severe weather conditions [20]. Growing legumes such as cowpea could, therefore, mitigate the GHG emission of paddy cultivation while adapting to harsh climatic conditions without disrupting crop yields.

IV. Conclusion

The study highlights the significant GHG emissions associated with paddy cultivation in Sri Lanka, particularly in the Ampara district. The research estimates the annual total GHG emissions from paddy, cowpea, and turmeric cultivation, identifying N_2O emissions from the soil as the largest contributor, followed by CH_4 and CO_2. The integration of crops like cowpeas into the paddy cultivation system demonstrates a potential reduction in total GHG emissions by 6.76%, proving that crop diversification can be an effective strategy for mitigating environmental impacts. Sustainable practices such as using biochar, composted rice straw, and deep placement of urea are recommended to reduce further the GWP of the integrated cropping system. The findings underscore the importance of adopting environmentally friendly agricultural practices to meet Sri Lanka's emission reduction targets and contribute to global climate change mitigation efforts.

References

[1] Rathnayake, H. and Mizunoya, T. (2023) 'A study on GHG emission assessment in agricultural areas in Sri Lanka: The case of Mahaweli H Agricultural Region', *Environmental Science and Pollution Research*, 30(37), pp. 88180–88196. doi:10.1007/s11356-023-28488-8.

[2] Wang, X. *et al.* (2023) 'Global and regional trends in greenhouse gas emissions from rice production, trade, and consumption', *Environmental Impact Assessment Review*, 101, p. 107141. doi:10.1016/j.eiar.2023.107141.

[3] Ahmed, Z. et al. (2022) 'Greenhouse gas emissions and mitigation strategies in Rice Production Systems', Global Agricultural Production: Resilience to Climate Change, pp. 237–265. doi:10.1007/978-3-031-14973-3_8.

[4] Mboyerwa, P.A. et al. (2022) 'Greenhouse gas emissions in irrigated paddy rice as influenced by crop management practices and nitrogen fertilization rates in eastern Tanzania', Frontiers in Sustainable Food Systems, 6. doi:10.3389/fsufs.2022.868479. K. Elissa, "Title of paper if known," unpublished.

[5] Zhang, L. *et al.* (2021) 'Examining the carbon footprint of rice production and consumption in Hubei, China: A life cycle assessment and uncertainty analysis approach', *Journal of Environmental Management*, 300, p. 113698. doi:10.1016/j.jenvman.2021.113698.

[6] Paramesh, V., Kumar, P., Parajuli, R., Francaviglia, R., Manohara, K. K., Arunachalam, V., ... & Toraskar, S. (2023). A life cycle assessment of rice–rice and rice–cowpea cropping systems in the west coast of India. *Land*, *12*(2), 502.J.

[7] Jahangir, M. M. R., Aguilera, E., Ferdous, J., Mahjabin, F., Al Asif, A., Ahmad, H., ... & Zaman, M. (2023). Carbon footprint and greenhouse gas emissions from rice based agricultural systems calculated with a co-designed carbon footprint calculation tool. *Biogeosciences Discussions*, *2023*, 1-31.

[8] Ji, Y. *et al.* (2024) 'Carbon Footprint Research and mitigation strategies for Rice-cropping systems in China: A Review', *Frontiers in Sustainable Food Systems*, 8. doi:10.3389/fsufs.2024.1375092.

[9] Plaza-Bonilla, D. et al. (2018) 'Carbon footprint of cropping systems with grain legumes and cover crops: A case-study in SW France', Agricultural Systems, 167, pp. 92–102. doi:10.1016/j.agsy.2018.09.004.

[10] Singh, A.K., Ghorai, A.K. and Kar, G. (2022) 'Diversification of rice growing areas in eastern India with integrated soil–crop system management for ghgs mitigation and higher productivity', *Carbon Management*, 13(1), pp. 105–116. doi:10.1080/17583004.2021.2023049.

[11] Arunrat, N. and Pumijumnong, N. (2017) 'Practices for reducing greenhouse gas emissions from rice production in northeast Thailand', *Agriculture*, 7(1), p. 4. doi:10.3390/agriculture7010004.

[12] Hussain, S., Peng, S., Fahad, S., Khaliq, A., Huang, J., Cui, K., & Nie, L. (2015). Rice management interventions to mitigate greenhouse gas emissions: a review. *Environmental Science and Pollution Research*, *22*, 3342-3360.

[13] https://www.climatechange.lk/Documents/A_Guide_for_Carbon_Footprint_Assessment.pdf

[14] https://www.ipccnggip.iges.or.jp/public/gp/bgp/4_5_N2O_Agricultural_Soils.pdf

[15] Akiyama, H., Yagi, K. and Yan, X. (2005) 'Direct N2O emissions from rice paddy fields: Summary of available data', *Global Biogeochemical Cycles*, 19(1). doi:10.1029/2004gb002378.

[16] Majumdar, D. *et al.* (2000) 'Reducing nitrous oxide emission from an irrigated rice field of north India with nitrification inhibitors', *Agriculture, Ecosystems & Environment*, 81(3), pp. 163–169. doi:10.1016/s0167-8809(00)00156-0.

[17] Epule, E.T., Peng, C. and Mafany, N.M. (2011) 'Methane emissions from paddy rice fields: Strategies towards achieving a win-win sustainability scenario between rice production and methane emission reduction', *Journal of Sustainable Development*, 4(6). doi:10.5539/jsd.v4n6p188.

[18] Yagi, K. *et al.* (2019) 'Potential and promisingness of technical options for mitigating greenhouse gas emissions from rice cultivation in Southeast Asian countries', *Soil Science and Plant Nutrition*, 66(1), pp. 37–49. doi:10.1080/00380768.2019.1683890.

[19] Hassan, M.U. *et al.* (2022) 'Management strategies to mitigate N2O emissions in Agriculture', *Life*, 12(3), p. 439. doi:10.3390/life12030439.

[20] Towprayoon, S., Smakgahn, K. and Poonkaew, S. (2005) 'Mitigation of methane and nitrous oxide emissions from drained irrigated rice fields', *Chemosphere*, 59(11), pp. 1547–1556. doi:10.1016/j.chemosphere.2005.02.009.

[21] Randeepanee, M. A. D. N., Basnayake, P. B. M. K. D. C. S., Wijayasenaratne, K. A. S. H., Gunawardhana, M. A. N. D., & Ariyawansha, R. T. K. (2023). Determination of the Climate Change Adaptability of Paddy-growing Farmers in Ampara District, Sri Lanka: A Case Study.

Sustainable Waste Management in the Paint and Coatings Industry: A Case Study of a Paint and Coatings Manufacturing Company in Sri Lanka

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Abstract: The case study was based on a paint and coatings manufacturing company in Sri Lanka to analyse its current waste management practices and provide recommendations for implementation based on global sustainable waste management practices in the paint and coatings industry which minimize environmental impact, optimize resource utilization, ensure regulatory compliance, and support a circular economy. The waste quantities and end of life of wastes generated were identified with a comprehensive waste audit. The carbon emissions from the waste disposal were calculated according to the UK government conversion factors for greenhouse gas reporting. The waste management practices implemented by the company were analysed in comparison with the existing best practices in the industry. In the year 2023/24, 3.58 tonnes of sludge was incinerated, 103.09 tonnes of all other hazardous waste was recycled, 0.40 tonnes of food and drink waste was sent to landfills, and 30.00 tonnes of all other non-hazardous waste was recycled. The carbon emissions from the disposal of sludge, e-waste, metal waste, plastic waste and food and drink wastes was 2.326 tCO2e. All the existing waste management practices implemented in the manufacturing facility are in accordance with Sri Lankan environmental regulations. Global best practices such as reducing, reusing, recycling, and incinerating of wastes are followed. The company can broaden its paint recycling, implement internal weighing of wastes and solar drying of sludge. The company can be more sustainable by continuously analysing the global trends in waste management and implementing those best practices within the company.

Keywords - paint and coatings industry, waste, sustainable, carbon emissions, UK government conversion factors for greenhouse gas reporting

I. INTRODUCTION

The paints & coatings industry is ever-growing with urbanisation, population growth, and rapid industrialization. 44% of global coating sales is from the Asia-Pacific region due to cheap labour and abundant resources [1]. Increased production and paint consumption may lead to generation of large amounts of waste which can lead to environmental pollution and affect the health of people. Since the industry has to supply the increasing demand for paints & coatings products, it is necessary to practice sustainable waste management practices to prevent possible environmental pollution due to the waste generated from the manufacturing processes. This case study focuses on analysing the waste-related issues in a manufacturing company in Sri Lanka and suggest possible solutions for waste minimization and pollution prevention for a sustainable waste management system. The current sustainable waste management practices followed in the world were studied by desk research and the feasibility of applying them to the local manufacturing company was analysed. According to the United States Environmental Protection Agency (US EPA), current waste minimization methods for equipment cleaning waste include using counter-current rinse methods, using high-pressure wash systems, using alternative cleaning agents, reuse equipment cleaning waste, etc. Air emissions are reduced by modifying bulk storage tanks, using pate pigments and installing dedicated baghouse systems [4]

Paints & coating industry produces wastes in all three categories of wastes: solid wastes, liquid wastes, and gaseous wastes. The predominant wastes generated include equipment cleaning wastes, outdated or returned paints, packaging wastes, paints spilled accidentally, air emissions etc. The water discarded after cleaning the equipment generates a large amount of wastewater (80%) in the manufacturing process [3]. This wastewater has the same chemical compounds as the input materials. The wastewater can contain high chemical oxygen demand and turbidity, besides organic matter, suspended solids, and heavy metals that cause enormous environmental damage [2]. This case study aimed to analyse the existing waste management practices and suggest sustainable waste management practices and technologies applicable for the manufacturing company and improvements to the existing waste disposal mechanisms. This case study will benefit the paint and coatings industry in the country as a reference for implementing sustainable waste management practices in the industry.

II. METHODOLOGY

Waste Audit

A waste audit was carried out to identify the types of waste generated, locations of waste generated, amount of waste generated, waste collection methods, waste disposal methods, issues in current waste management practices, and possible improvements that can be implemented for sustainable waste management in the manufacturing facility. To identify the waste types, waste quantities, and waste generated locations site visits were conducted at the manufacturing facility. Site visits provided a clear understanding of the wastes generated

in the manufacturing facility. With the aid of the site visits which were conducted at the manufacturing facility, the relevant data needed for the waste audit were gathered. The waste audit was conducted as per the Guide to Waste Audits and Waste Reduction Work Plans for Industrial, Commercial, and Institutional Sectors under Ontario Regulation 102/94 in Canada [13]

The waste audit conducted aided in finding the amount, nature, and composition of the waste generated in all functional areas of the entity, how the waste is produced, including relevant management decisions and policies, how the waste is managed, and the extent to which materials or products used or sold consist of recycled or reused materials or products. The scrap records that were available with the manufacturing facility were used in identifying the types and quantities of waste generated. The annual scrap record of the manufacturing facility consisted of the types of wastes generated during that time which were collected by the third-party waste collectors. Scrap records of two consecutive years, 2023 and 2022, were taken from the manufacturing facility. A comparison of the wastes generated from the two years was done based on the information taken from the scrap records. The types and quantities of waste generated at specific locations in the manufacturing facility were found at the end of the waste audit.

The waste audit includes all administrative, warehousing, or other ancillary activities or departments located on the same site and associated with the designated entity. The types of wastes generated at each specific location were found after the site visits were completed. Based on the findings of the waste audit the sustainable waste management practices were analysed. The existing best practices in the industry were identified through desk research and compared with the existing practices in the company.

Carbon emission calculation

The waste quantities found from the waste audit were used in calculating carbon emissions from the waste disposal methods. For the calculations, UK government conversion factors for greenhouse gas reporting were taken. The relevant waste disposal method was taken as the activity data, and this was multiplied by the relevant emission factor given by the UK standard. The waste quantity was converted to tonnes before being multiplied by its emission factor. The relevant tCO2e (tonnes of carbon dioxide equivalent) value for the waste disposal methods was the product of the activity data and relevant emission factor. The tCO2e value obtained by this calculation is the annual carbon dioxide emissions related to the waste disposed of in a time period of one year. The GHG emissions for waste disposal methods are given in kgCO2e. The waste disposed data have to be converted into tonnes to be used in Eq. 1.

$$GHG\ emissions = Activity\ data \times Emission\ conversion\ factor \quad (1)$$

The final disposal method was identified based on the information taken from the third-party waste collectors. All the third-party waste collectors associated with the company are the Central Environmental Authority (CEA) of Sri Lanka-approved waste collectors. This ensures that the wastes generated in the manufacturing facility are disposed of in an environmentally friendly and standard manner. The impact from the waste generation at the manufacturing facility on the environment is thereby reduced significantly.

III. Results and Discussion

Manufacturing Process

Generalised manufacturing processes can be simplified into inputs, processes and outputs. The general inputs are the raw materials, electricity and water. The processes include grinding, mixing, cleaning of vessels and vessel hygiene. Outputs include final paint products, vessel washing water, plastic waste, paper/cardboard waste, gaseous emissions, chemical spills and cotton waste. These can be slightly varied depending on the products manufactured and the processes followed.

Waste Management in the Manufacturing Facility

The company has implemented waste management practices in order to keep the premises clean while ensuring the waste generated does not impact the surrounding environment. As per the regulations stipulated under the Part II of the National Environmental (Protection & Quality) Regulations No 01 of 2008 all persons involved in the handling of (Generate, Collect, Transport, Store, Recover or Recycle and Disposal of waste or establish any site or facility for the disposal) Scheduled Waste specified in the Schedule VIII of the regulation should obtain a licence from the CEA. The company has obtained this Scheduled Waste license from the CEA. The company which belongs to the category number 12 (Paints (emulsion or enamel), inks, pigments, varnish, polish manufacturing or formulating industries) of Part A of the Schedule published in Gazette Extraordinary No. 1159/22 dated 22.11.2000 under The National Environmental Act, No. 47 of 1980 has obtained the Environmental Protection Licence.

There are three types of wastes which can be identified in the manufacturing facility which are solid waste, liquid waste and gaseous waste. The company has taken several steps to manage the wastes to ensure that no hazardous chemicals are released to the natural environment. These waste types identified from the waste audit can be categorized based on the location as given below in Table 1.

Table 1 Location-wise waste types

Location	Solid wastes	Liquid Wastes	Gaseous Emissions
Water base	Packing material waste, Cotton waste	Machine cleaning wastewater, Floor cleaning wastewater, Chemical Spills	
Emulsion	Packing materials waste, Cotton waste	Machine cleaning wastewater, Machine hygiene wastewater, Floor cleaning waste water, Chemical Spills	Chemical dust

Solvent based paints	Contaminated drums, Packing material waste, Cotton waste	Floor cleaning wastewater, Chemical Spills	VOC emissions
Enamel	Contaminated drums, Packing materials waste, Cotton waste	Waste water, Floor cleaning wastewater, Chemical Spills	
Cafeteria	Food waste, Paper towels, Plastic waste	Wastewater from sinks	
Offices	Paper waste, Face towels/tissues		
Warehouses	Paper waste, Cardboard, Polythene waste, Plastic waste, Metal, Cotton waste	Chemical Spills	Dust
Washrooms	Toilet papers	Sewerage waste, Wastewater from sinks	
Generator room			Smoke

Solid Waste Management

The solid wastes generated within the manufacturing facility are disposed of by third-party waste collectors. Since all of these waste collectors are approved by the CEA it can be ensured that these wastes are disposed of in the most environmentally friendly way available. The sludge is collected by a CEA approved third-party hazardous waste incinerator and incinerated at an external incineration plant. The wastes contaminated with paints and chemicals are considered as hazardous wastes and are treated accordingly. The company has ensured that all the solid wastes generated inside the manufacturing facility are being properly disposed of by the third-party waste collectors.

The manufacturing facility has implemented a waste collection system where colour coded bins are kept at each location of manufacturing so that all the waste generated in that specific section is collected at the source of generation. At the central waste collection point hazardous and non-hazardous wastes are collected separately. This contains all the solid wastes generated within the manufacturing facility and stores temporarily until they are collected by the third-party waste collectors. The Table 2 given below shows the end of life of different types of waste categories.

Table 2 End of life of wastes

Waste Type	Collected by	End of life
Metal	Third-party waste collector	Recycled
Paper and board	Third-party waste collector	Recycled
Plastics: LDPE	Third-party waste collector	Recycled
Plastics: average plastics	Third-party waste collector	Recycled
Plastics: PP	Third-party waste collector	Recycled
Plastics: HDPE	Third-party waste collector	Recycled
E-waste	Third-party waste collector	Recycled
Sludge	Third-party waste collector	Incinerated
Food waste	Third-party waste collector	Sent for landfills

The company gets the waste records from the third-party waste collectors after the collection of wastes. There is no mechanism to measure these waste quantities inside the manufacturing facility except for the recent measuring of food waste. The factory management implemented a new system to weigh the food waste generated in the manufacturing facility. The food waste generated in a day is around 15 kg per day. Food patterns are studied based on the waste quantities generated and steps were taken to make changes to the menu of lunch served which resulted in reducing the food waste from 15 kg to 9 kg per day.

The manufacturing facility receive return paints are reprocessed or incinerated based on the condition of the received paints. The received paints are tested for their quality and reprocessed if the required conditions are met. This prevents the wastage of resources and minimise the impact on the environment significantly. This recycling of paints is also a practice followed in the global paint industry [15,16]. If the received paints are not in a condition to be send for reprocessing, those paints are sent to be incinerated. The CEA approved third-party incineration company who is responsible for the incineration of sludge generated from the wastewater treatment plant collects these discarded paints as well and incinerate at their incineration plant.

Liquid Waste Management

The liquid waste generated within the manufacturing facility can be categorised into two types as hazardous and non-hazardous. The hazardous liquid wastes are the wastewater from washing the vessels used to mix paints and machinery. The non-hazardous liquid wastes are the sewerage waste from toilets and the grey water from the cafeteria and the washrooms. All the liquid wastes generated within the manufacturing facility is sent to the wastewater treatment plant to be treated. The treatment plant treats the wastewater biologically and chemically. Industrial wastewater is sent to a primary sedimentation tank before it is sent to a clarifier tank where chemical treatment is done. Then it is sent through a sand bed filtering system before it is sent to the secondary collection tank where sewerage water is also added. The aeration system is placed before it is sent to the secondary clarifier tank which then is sent to the final collection tank. Finally, it is filtered with a carbon and sand filter. The treated water is sent to a collection pond where the water is absorbed or evaporated gradually. According to the last years records the total treated water discharged was recorded as 504.97 m^3.

Regular tests are carried out by the internal laboratory to ensure that the treated water released is within safe Biochemical oxygen demand (BOD) and Chemical oxygen demand (COD) levels. Treated water is also tested by CEA accredited third-party laboratories quarterly. BOD is maintained at a level below 30 mg/L and COD is maintained

at a level below 250 mg/L. The pH at ambient temperature is maintained between 6.0 – 8.5. The temperature of discharge is maintained less than 40 ºC. The total suspended solids (TSS) level is maintained below 50 mg/L. These are according to the tolerance limits for the discharge of industrial effluent into inland surface waters given under the regulations of the National Environmental Act No. 47 of 1980.

Gaseous Emission Management

The company has significantly removed the volatile organic compounds (VOC) content in most of the emulsion paint products by having altered the chemical formulae of the paints. The company conducts Non-methane Volatile Organic Compounds (NMVOC) tests yearly from a CEA accredited third-party laboratory to ensure the fugitive NMVOC emission at the process area is within the limits of Fugitive Non-Methane Volatile Organic Compounds (NMVOC) Emission Standards. The related Sri Lankan regulation is the Schedule V, Regulation 4, Fugitive Non-Methane Volatile Organic Compounds (NMVOC) Emission Standards made by the Minister of Environment under Stationary Sources Emission Control Regulation, No 1 of 2019. Extraordinary Gazette No.2126/36, 05 June 2019. It states that the difference between two simultaneous Non-Methane Volatile Organic Compound (NMVOC) measurements from any process area shall not be greater than 5 ppm and the measurement location shall be within 5 meters from any process equipment or emission area towards up - wind and down - wind directions.

Dust emissions occur when loading chemical powders into the mixing machines during paint production. These dust emissions are gathered by bag housing systems to prevent them adding into the surrounding environment. The company conduct tests yearly for fugitive dust emissions to ensure that the fugitive dust emissions are within the standard limits. Total Suspended Particulate Matter (TSPM) level is the parameter tested under this test. The related Sri Lankan regulation is the Schedule IV, Regulation 4, Fugitive Dust Emission Standards made by Ministry of Environment under Stationary Sources Emission Control Regulation, No 1 of 2019. Extraordinary Gazette No.2126/36, 05 June 2019. It states that the differences between two simultaneous 3-hour Total Suspended Particulate Matter (TSPM) measurements (gravimetric) carried out up-wing and down-wind basis from emission area or process area shall not be greater than 450 µg/m3 and the measurement location shall be within 10 m from any process or emission area towards up-wind and down-wind directions.

Smoke is emitted from generators when generating electricity during power cuts. The smoke opacity level is tested yearly under this emission test. The related Sri Lankan regulation is the National Environmental Act, No. 47 of 1980, Regulations under Section 32, SCHEDULE II, Instrument/equipment-based standards, Part II. Thermal Power Plants-Standby Generators (Any). Since the fuel used is diesel, Regulation 12 is not applicable as there are no significant SO_2 emissions. There are no smoke emissions within the factory related to manufacturing operations such as boilers.

Quantities of Solid Waste Generation

The waste generated for two consecutive years were identified from the waste audit and scrap records (see Table 3, Table 4, Table 5, Table 6). Scrap records are obtained from the third-party waste collectors who are responsible for the disposal of wastes generated within the manufacturing facility.

Table 3 Non-hazardous Waste Quantity 2023/24

Waste type	Quantity (tonnes)
Wood	15.28
Organic: food and drink waste	0.40
Metal: scrap metal	6.62
Paper and board: board	2.79
Plastics: LDPE	1.99
Plastics: average plastics	3.33
TOTAL	30.40

Table 4 Non-hazardous Waste Quantity 2022/23

Waste type	Quantity (tonnes)
Wood	6.93
Garbage bags	22.20
Disposable Metal	5.54
Metal drums	0.14
Cardboard	3.84
Disposable Aluminium Scrap	2.21
Polythene	3.51
TOTAL	44.37

Table 5 Hazardous waste quantity 2023/24

Waste type	Quantity (tonnes)
E-waste	0.14
Sludge	3.58
Metal: steel cans	75.81
Plastics: PP	22.48
Plastics: HDPE	4.67
TOTAL	106.67

Table 6 Hazardous Waste Quantity 2022/23

Waste type	Quantity (tonnes)
Sludge	0.84
Metal Drums	12.55
Tins	3.65
Plastic Drums	2.27
Plastic buckets	0.25
Wastewater + drum	0.05
Plastic cans and disposal plastic	5.95
IBC (Intermediate Bulk Container) Tank	2.38
TOTAL	27.93

Carbon Footprint Calculation

UK Government GHG Conversion Factors released by the Department for Energy Security and Net Zero and Department for Business, Energy & Industrial Strategy of UK were used for the calculation of GHG emissions related to the waste disposal of the company. The latest version (V1.1) which was released in the year 2023 was used for the calculations. The GHG emissions for waste disposal methods are given in $kgCO_2e$.

Waste Related Carbon Emissions

The waste quantities identified by the waste audit are used in calculating the carbon emissions related to the waste disposal. The activity data of the waste types which has the emission factors in the UK Government GHG Conversion Factors are only taken into consideration when calculating the carbon emissions. The calculation is given in Table 7 below.

Table 7 tCO2e calculation for solid wastes

Activity data	Quantity (tonnes)	Emission conversion factor ($kgCO_2e$)	tCO_2e value
Sludge	3.58	21.2808	0.0761
E-waste	0.14	21.2808	0.0029
Metal	82.43	21.2808	1.7541
Plastics (HDPE, LDPE, average)	10	21.2808	0.2128
Organic: food and drink waste	0.40	700.210	0.2801

Here the sludge, e-waste, metal waste, plastic waste (HDPE, LDPE, average) and food and drink wastes were considered. The emission factors are related to the end of life of those waste types. Sludge has the emission factor related to incineration. E-waste, metal waste and plastic waste (HDPE, LDPE, average) has the emission factor related to recycling. The emission conversion factor is given in the standard by $kgCO_2e$. The quantity of wastes has to be taken in tonnes as per the requirement of the standard and hence the waste quantities were taken in tonnes. Then the quantity of waste was multiplied by the emission conversion factor which result in the $kgCO_2e$ emitted from those waste disposed. These values were divided by thousand to get the tCO_2e value which is the standard unit used for carbon emissions. Since the company has already implemented the recycling of these wastes which is a best practice in the industry, the carbon emissions also have a low impact on global warming.

Fuel Related Carbon Emissions

The major activity that releases CO_2 is the electricity generation during power cuts by the onsite generator. Only 300 L of diesel was utilized from April 2023 to March 2024. The emission factors related to diesel fuel consumption in the UK Government GHG Conversion Factors are considered for the carbon emission calculation. The volume of diesel used is taken in litres and multiplied by the relevant emission factor in the standard. Then the resulting $kgCO_2e$ value is divided by thousand to get the tCO_2e value. The calculation is given in the Table 8 given below.

Table 8 Diesel related carbon emission calculation

Activity data	Quantity (L)	Emission factor ($kgCO_2e$)	tCO_2e value
Diesel	300	2.6593	0.7978

Technological Innovations and Their Impact

The raw materials and packing materials are send through a material screening process before acquisition by the company. The company has its own evaluation index for both raw materials and packing materials. This ensures that all the raw materials and packing materials are safe to be used in products. The suppliers are also screened based on environmental and social factors which ensures suppliers are practicing green practices. The acquired chemicals are then stored according to chemical storing compatibility chart and material safety data sheets (MSDS). These steps ensure that the company acquires low-impact raw materials and packing materials throughout their production.

The company has reduced the VOC content of their emulsion range products up to <2 $\mu g/m^3$ where the normal products in the market are having $<5\times10^{10}$ $\mu g/m^3$ VOC level. There are no Alkylphenol ethoxylates (APEOs) and heavy metals (Sb, Ba, Cd, Cr, Co, Cu, Pb, Mn, Sr, and Zn) in the product range which reduces the impact on the environment significantly. This is achieved by improving the product formulae through continuous research and innovations. Since the chemicals present in the products are less harmful to the environment, the company has set a benchmark for local paint manufacturers to make their products also with less impact on the environment. The company has encouraged the employees to be a part of the company's sustainable initiatives by getting their novel ideas for innovations. An overnight resin collector stand was made to scrape out all the materials remaining in the barrels. This was a recently implemented novel idea brought up by the employees which reduce the wastage of valuable raw materials during the production process. Such small initiatives foster a culture of sustainability within the company encouraging innovations leading to sustainable technologies.

Environmental and Economic Outcomes

The environmental impact reduced significantly by the material evaluation indexes and the supplier screening process. When APEO metabolites are released into the environment, they have a negative impact on wildlife, people, and the ecosystem [19]. By removing APEOs from the products the impact it can cause on the ecosystems is eradicated. By removing heavy metals from the products, the impact they can cause on the environment is also eradicated. Hence by altering the formulae of products, the company has prevented the possible harmful outcomes from the addition of these chemicals into the environment. The company practices the industry best practices such as recycling wastes which can be recycled such as plastics, metals, cardboard, etc. The returned products also are reprocessed into new products based on their condition. This reduces the dependability on virgin raw materials while reducing the number of hazardous wastes sent for incineration. This leads to resource conservation and contributes to a circular economy.

Challenges and Barriers Faced

One of the main challenges faced by the company in managing the wastes generated in the manufacturing facility

is the lack of space for the storage of the wastes. The centralized waste collection centre in the facility can be improved to store more wastes to reduce the frequency of wastes being transported by the third-party waste collectors. The existing collection centre is a part of a building, and this can be improved by having a separate building dedicated for the waste storage only. In the current location the wastes are stored in IBCs, barrels or in polythene bags depending on the nature of the wastes. A new building space can be proposed to collect the wastes separately based on the nature; hazardous and non-hazardous. This could also help in storing excess of wastes generated when the production is higher than the normal. The company pays the third-party incineration company to collect the sludge generated in the facility. This cost is calculated based on the weight of the sludge and the distance the sludge is transported to the incineration plant. At present there is no mechanism to dry the sludge produced from the wastewater treatment plant. The water content in the sludge is evaporated by natural means. Hence the company has to incur a cost inclusive of the wet content of the sludge. This can be reduced by having a system to dry the sludge generated. A solar drying system can be suggested since it will be cost effective and environmentally friendly.

Comparative Analysis with Global Best Practices

Global giants in the paint industry such as Nippon and Sherwin Williams have taken steps to recycle their leftover paints. This is done at the local company only for the returned paints. A paint take-back program can be proposed to be implemented in the company so that the recycling paint quantity can be increased which leads to more resource conservation and pollution prevention. Nippon and Sherwin Williams recover solvents from the waste solvent generated from the cleaning process equipment. This also leads to resource conservation and pollution prevention. This recycling of waste solvents can be improved in the local company also. Sherwin Williams practices repurposing goods and materials so they can be used again rather than being thrown away. This is also practiced at the local company in instances such as utilizing the barrels and drums for the collection of wastes and mixing chemicals [15,16].

Recycling of wastes like cardboard, paper, plastic, and metal is practiced by Sherwin Williams which is a practice followed by the local company also. Sherwin Williams clean the container surfaces which improves the capacity to recycle. These containers then can be shredded and sent for the recyclers. This will increase the quantity of materials being recycled. This practice can also be suggested to be implemented at the local company. Weighing of wastes can also be implemented in the local company. These practices will ultimately lead to a sustainable waste management in the local paint and coatings manufacturing company [15,16].

IV. Conclusion

The waste management practices implemented currently in the Sri Lankan paint and coatings manufacturing company are in line with the local environmental regulations and the company has obtained the scheduled waste license from the CEA. The waste audits conducted showed that the hazardous waste generated exceeds the non-hazardous waste generated in the last year. The weight of sludge can be decreased by implementing a drying system such as a solar dryer. The company has reduced the liquid waste generation by using pressure washers for vessel cleaning. This also reduced the water consumption needed for waste disposal. The colour coded waste segregation at collection points resulted a more organised and cleaner environment in the manufacturing premises. Recycling of plastics, metals and cardboard is a commendable practice of the local company. The food waste reduction by weighing the food waste also is a creditable practice which can be applied for other waste types as well. The carbon emission calculation also helped the company keep a track on the emissions related to waste disposal. This hazardous waste generated can be minimised by implementing new methods like making bricks from the sludge. Recycling of vessel wash water can also be implemented which can reduce the excessive consumption of resources. The reprocessing of returned paints can be broadened into a paint take-back program which can increase the circularity of products. The waste records of the company can be increased by weighing the wastes internally rather than taking it from scrap records. Overall, the company has set a plausible benchmark for other local paint manufacturers. This case study will be helpful for the local paint industry to analyse their waste management practices and implement industry best practices in their companies. The local company taken for the case study can continuously improve its waste management practices in a sustainable manner by analysing the global trends in waste management in the paint and coating industry.

V. Acknowledgment

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References

[1] Noruzman, A.H. and Apandi, N.M., 2020. Paint waste management in industry. Journal of Advanced Research in Business and Management Studies, 20(1), pp.28-33.

[2] Nair, S., Manu, B. and Azhoni, A., 2021. Sustainable treatment of paint industry wastewater: Current techniques and challenges. Journal of Environmental Management, 296, p.105-113.

[3] Lorton, G.A., 1988. Hazardous waste minimization: Part III waste minimization in the paint and allied products industry. Japca, 38(4), pp.422-427.

[4] Risk Reduction Engineering Laboratory and Center for Environmental Research Information (1990). Guide to Pollution Prevention: The Paint Manufacturing Industry. US EPA. [Accessed 30 Jun. 2024].

[5] Dursun, D. and Sengul, F., 2006. Waste minimization study in a solvent-based paint manufacturing plant. Resources, conservation and recycling, 47(4), pp.316-331.

[6] Mostafa, M.K. and Peters, R.W., 2017. Reuse paint wastewater in the manufacture of cement bricks and tiles. Journal of Material Cycles and Waste Management, 19, pp.840-850.

[7] Environment, U.N. (2017). Solid waste management. [online] UNEP - UN Environment Programme. Available at: https://www.unep.org/explore-topics/resource-efficiency/what-we-do/cities/solid-waste-management#:~:text=Where%20waste%20cannot%20be%20avoided [Accessed 30 Jun. 2024].

[8] United Nations (n.d.). Sustainability. United Nations. [online] Available at: https://www.un.org/en/academic-impact/sustainability [Accessed 30 Jun. 2024].

[9] Pandey, D., Agrawal, M. and Pandey, J.S., 2011. Carbon footprint: current methods of estimation. Environmental monitoring and assessment, 178, pp.135-160.

[10] Bennamoun, L., 2012. Solar drying of wastewater sludge: A review. Renewable and Sustainable Energy Reviews, 16(1), pp.1061-1073
[11] Onyeji, L.I., 2010. Recovery and analysis of solvents from waste in paint industry. Continental Journal of Environmental Sciences, 4(44), p.2010.
[12] Viktoryová, N., Szarka, A. and Hrouzková, S., 2022. Recent developments and emerging trends in paint industry wastewater treatment methods. Applied Sciences, 12(20), p.10678.
[13] Yapıcıoğlu, P., 2018. Investigation of environmental-friendly technology for a paint industry wastewater plant in Turkey. Süleyman Demirel Üniversitesi Fen Bilimleri Enstitüsü Dergisi, 22(1), pp.98-106.
[14] Ministry of the Environment, Government of Ontario (2008). Waste Audits and Waste Reduction Work Plans. [online] Available at: https://dr6j45jk9xcmk.cloudfront.net/documents/3939/ici-guide-revised-july-08.pdf. [Accessed 2 Apr. 2024].
[15] Department for Energy Security and Net Zero and Department for Environment Food & Rural Affairs (2023). UK Government GHG Conversion Factors for Company Reporting. [online] Available at: https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2023 [Accessed 2 Apr. 2024].
[16] Nippon Paint Holdings Co.,Ltd. (n.d.). Waste and resources. [online] Available at: https://www.nipponpaint-holdings.com/en/sustainability/environment/waste/ [Accessed 30 Jun. 2024].
[17] Sherwin Williams (n.d.). SHERWIN WILLIAMS 2022 SUSTAINABILITY REPORT. [online] Available at: https://s2.q4cdn.com/918177852/files/doc_financials/2022/ar/sherwin-williams-2022ar-web-nohyperlinks.pdf [Accessed 30 Jun. 2024].
[18] Gao, T., Liu, Q. and Wang, J., 2014. A comparative study of carbon footprint and assessment standards. International Journal of Low-Carbon Technologies, 9(3), pp.237-243.
[19] El-Fadel, M., Zeinati, M., El-Jisr, K. and Jamali, D., 2001. Industrial-waste management in developing countries: The case of Lebanon. Journal of Environmental Management, 61(4), pp.281-300.
[20] Acir, I.H. and Guenther, K., 2018. Endocrine-disrupting metabolites of alkylphenol ethoxylates–a critical review of analytical methods, environmental occurrences, toxicity, and regulation. Science of the Total Environment, 635, pp.1530-1546.

An Analysis between Flood Damage and Economic Growth in Bangladesh Amid Changing Precipitation Dynamic

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Abstract- **Precipitation indices over recent years indicate an upward trend in rainfall for all over Bangladesh. As, Bangladesh is an extremely riverine country, the increased rain and flood caused enormous loss for the last few decades. However, with improved infrastructure and climate resiliency, the damage caused by these events has seen a relative decline. To understand the economic impact of precipitation and flood-related damages, this study explores the relationship between damage due to flood and rain and Bangladesh's GDP. Utilizing data from the World Development Indicators (WDI), the World Bank, and the Government of Bangladesh's Delta Plan 2100, a regression analysis was conducted to evaluate the correlation between flood-induced damage and GDP. The results show a non-significant negative correlation, indicating that while economic growth may mitigate the proportionate financial losses from flooding, the statistical relationship remains weak. This lack of significance is likely attributed to Bangladesh's high exposure to cyclones and extreme weather events, which introduces variability in the damage estimates and results in a non-linear damage-GDP relationship. These findings suggest that annual damages are inconsistent, with no clear trend due to the irregular occurrence of cyclones. This study highlights the importance of improving disaster preparedness and climate resilience strategies, particularly in cyclone-prone areas. Additionally, it underscores the need for more sophisticated statistical models that can better account for the complexities of disaster-related economic losses. Future research should focus on incorporating these factors to provide a more comprehensive understanding of the financial impacts of climate change in Bangladesh.**

Keywords: Flood Damage, Economic Growth, Precipitation Indices, Bangladesh, Climate Change, GDP

I. INTRODUCTION

Bangladesh being a deltaic nation in South Asia, is exceedingly susceptible to the effects of extreme meteorological phenomena like, intense precipitation and flooding. The nation's physical position, adjacent to the Bay of Bengal and intersected by significant rivers like the Ganges, Brahmaputra, and Meghna, renders it susceptible to seasonal inundation and monsoon-induced calamities. Intense precipitation frequently induces substantial floods, resulting in significant damage to infrastructure, crops, and human habitation. Recent weather extremes have heightened concerns regarding their possible long-term effects on the nation's economy, especially its Gross Domestic Product (GDP). Consequently, it is important to conduct a comprehensive analysis of precipitation indices to comprehend the phenomena related to the frequency and severity of heavy rainfall.

Precipitation indices are quantitative metrics employed to characterise many characteristics of precipitation, including its intensity and temporal frequency, which are crucial for comprehending variability and trends in precipitation patterns. The Standardised Precipitation Index (SPI) is a widely utilised precipitation metric that measures shortfalls or surpluses in precipitation over a designated time frame. The Standardised Precipitation Index (SPI) is especially effective for assessing drought conditions, as it normalises precipitation data to facilitate comparisons across various locations and temporal periods[1]. The Precipitation Concentration Index (PCI) is a significant metric that assesses the distribution of precipitation during a specified duration, reflecting the concentration or dispersion of precipitation events during that period [2]. Elevated PCI values indicate that precipitation is concentrated in a limited number of episodes, thereby heightening flooding concerns, whereas diminished values reflect a more uniform distribution of rainfall. In addition to these indices, this study examines extreme precipitation indices, including RX1day (the maximum daily precipitation) and RX5day (the maximum precipitation over five consecutive days), which are essential for comprehending the frequency and intensity of extreme weather events [3]. These indices are especially pertinent to

climate change, since they assist in identifying trends in extreme precipitation events that may result in flooding and other hydrological risks [4]. The incidence of extreme precipitation events is rising worldwide, presenting considerable threats to infrastructure, agriculture, and water management systems [5], [6]. The correlation between precipitation indices and climatic parameters, including temperature and air circulation patterns, is essential for comprehending the mechanisms influencing alterations in precipitation [7]. The impact of teleconnection patterns, such as the El Niño Southern Oscillation (ENSO)[8], can substantially influence precipitation variability across various regions [9]. Comprehending these interactions is essential for refining climate models and augmenting the precision of precipitation predictions. The correlation among precipitation indices, flooding, and economic performance in Bangladesh is a vital subject of investigation, especially considering the nation's susceptibility to climate change. Bangladesh endures substantial rainfall, with yearly precipitation differing markedly among regions, resulting in recurrent flooding that has serious socio-economic consequences. The Bangladesh Meteorological Department (BMD) has indicated rising trends in annual precipitation and the occurrence of extreme weather events, which are associated with the nation's economic difficulties, especially in the agricultural sector [10], [11]. Recent studies reveal a pattern of escalating yearly precipitation in Bangladesh, with considerable ramifications for both wet and dry seasons. Shahid's research indicates that yearly rainfall has increased by around 5.53 mm per year, especially in the western portions of the country, which are more vulnerable to flooding[12]. The examination of precipitation features from 1950 to 2008 indicates an increase in total annual precipitation and the frequency of wet days at multiple meteorological stations [11]. The escalation in rainfall intensity correlates with a heightened occurrence of extreme weather phenomena, such as intense precipitation and ensuing flooding, which provide considerable threats to agricultural productivity and economic stability [10].

II. METHODOLOGY

II.A. Data Source

The primary objective is to evaluate the relationship between flood damage (in BDT Crore) and GDP by utilizing secondary data from reputable sources like the World Bank and the Government of Bangladesh. Damage due to river and rainfall floods (in Crore BDT per year) was collected from Bangladesh 2100 Delta Plan Knowledge Portal of General Economics Division (GED) of Bangladesh Planning Commission. On the other hand, GDP (current LCU) has been collected from World Bank national accounts data, and OECD National Accounts data files through WDI (World Development Indicators Databank). GDP at purchaser's prices is the sum of gross value added by all resident producers in the economy plus any product taxes and minus any subsidies not included in the value of the products[13]. It is calculated without making deductions for depreciation of fabricated assets or for depletion and degradation of natural resources. GDP Data are in current local currency[14]. The GDP is taken in current LCU because the calculation of the floods related loss has been also calculated just after the incidence of any catastrophic event and audited annually by the Government of Bangladesh.

II.B Data Collection

Table I. Flood damage and GDP amount [13], [15]

Year	Damage by river and rainfall flood (Cr. BDT)	GDP (Cr. BDT)
1990	46480.2	103958.55
1991	56518.96	110518.22
1992	26160.47	119542.46
1993	28626.23	125369.44
1994	37689.88	135412.33
1995	21026.6	152517.79
1996	36936.29	189933.4
1997	22331.64	206003.2
1998	37103.56	226929.9
1999	26358.82	246508.9
2000	32008.97	268503.4
2001	56440.68	291337
2002	41882.58	314280.4
2003	30680.14	348320.2
2004	29438.45	383294
2005	33771.43	427074.1
2006	29994.57	482336.97
2007	53578.18	549799.7
2008	32024.86	628682.2
2009	30571.55	705071.8
2010	36377.08	797538.7

2011	32011.41	915828.8
2012	22501.25	1055204.04
2013	25926.37	1198923.17
2014	30989.97	1343674.4
2015	28306.4	1515802.3
2016	23563.44	2075821.1
2017	24245.32	2324307.2
2018	45222.27	2639248.1
2019	23050.09	2951428.5
2020	37968.89	3170469.4

II.C Simple Linear Regression Analysis

A linear regression model is used to either produce anticipated values or draw conclusions about relationships in the dataset. In certain areas, the predictor is referred to as the independent variable and the outcome as the dependent. Since dependent and independent have so many different implications in statistics, we refrain from using them in this way. A simple linear regression model for an outcome □ as a function of a predictor □ takes the form:

$$□□ = □0 + □1□□ + □□, \text{ for } □ = 1, ..., □$$

(1) where □ represents the number of observations (rows) in the data set.[16]

A linear regression model was constructed using the damage from floods as the independent variable (X) and GDP as the dependent variable

(Y). The regression was analyzed at confidence intervals of 0.90, 0.95, and 0.99 to assess the significance of the results.

II.D Coefficient Analysis

The relationship between GDP and flood damages was evaluated using coefficient analysis, t-values, and p-values to determine statistical significance.

III. RESULT

The data regarding loss due to floods and rain has been archived in the table. There is also a graphical representation of the loss all over Bangladesh through spatial view.

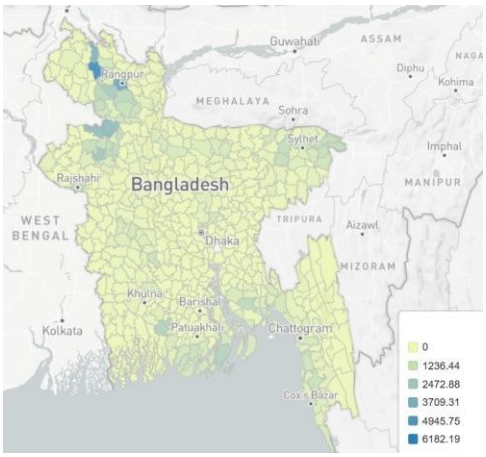

Fig. 1. District wise Damage by river and rainfall flood (Annual Average) [15]

Table II. Coefficient Analysis

Variables	Coefficient Estimates	Standard Error	t-value	p-value
Intercept (GDP in Crore BDT)	1406653.19	584291.19	2.407	0.0227
X (damage by river and rainfall flood in Crore BDT/Year)	-16.93	16.74	-1.011	0.3204

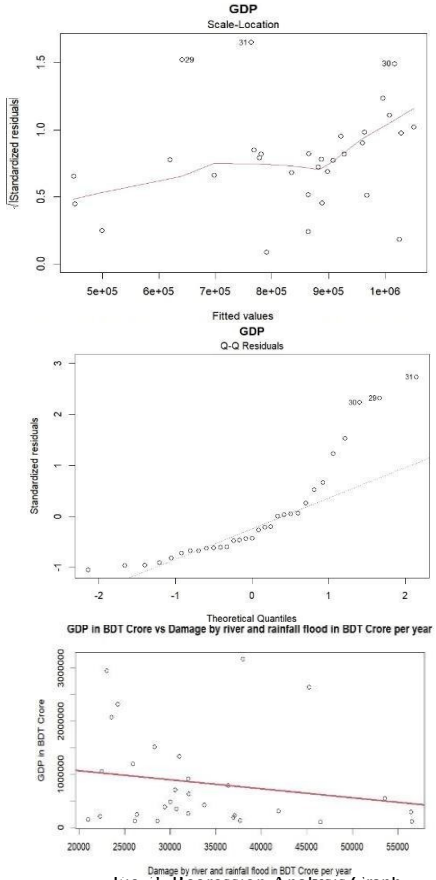

Fig. 2. Regression Analysis Graph

Table III. Analysis of Correlation types

Variables	Confidence level	Confidence (%)	Equation Coefficients	Correlation Type
Intercept (GDP in Crore BDT)	0.9	5%	413868.2286	Negative
X (damage by river and rainfall flood in Crore BDT/Year)			-45.37946	
Intercept (GDP in Crore BDT)	0.9	95.00%	2.40E+06	positive and almost zero
X (damage by river and rainfall flood in Crore BDT/Year)			1.15E+01	
Intercept (GDP in Crore BDT)	0.95	2.50%	211643.5178	Negative
X (damage by river and rainfall flood in Crore BDT/Year)			-51.17465	
Intercept (GDP in Crore BDT)	0.95	97.50%	2.60E+06	positive and almost zero
X (damage by river and rainfall flood in Crore BDT/Year)			1.73E+01	
Intercept (GDP in Crore BDT)	0.95	97.50%	-203878.8241	Negative
X (damage by river and rainfall flood in Crore BDT/Year)			-63.08234	
Intercept (GDP in Crore BDT)	0.95	97.50%	3.02E+06	positive and almost zero
X (damage by river and rainfall flood in Crore BDT/Year)			2.92E+01	

The linear regression model derived from the data on damage inflicted by river and rainfall floods in Crores BDT/year and GDP in Crores demonstrates a predominantly negative connection. The relevance is considerably greater for higher confidence value percentages than for lower percentages. The general linear regression equation, which accounts for damage inflicted by river and rainfall floods in Crores BDT per year (Y) as an independent variable affecting GDP in Crores (X), is expressed as Y = 1406653.19 - 16.93X. A negative correlation is illustrated here. This equation indicates elevated probability approaching 0, placing it in the rejection zone, therefore signifying significance for confidence intervals α=100%, 99.999%, 99.99%, and 99.95%, while demonstrating negligible importance for confidence ranges α=99.90% and 99%. The negativity continued because of an elevated mistake rate resulting in a standard error of 897,400.

Upon thorough examination of the p-value by ANOVA synthesis of the linear regression model, it was shown that the probability value is p=0.3204, with the corresponding statistic F=1.022. The p- value exceeds 0.05, indicating that the value resides within the recognized zone, hence suggesting an almost negligible or negative correlation between GDP in crores and the damage inflicted by river and rainfall floods in Cr. BDT/year. The R-Squared value of the model is 0.03405, indicating that the model is nearly unfit and accounts for 3.4% of the variability in GDP in Crores. Upon examining the graph produced by the linear regression in conjunction with the red line, it is evident that the majority of the data points are non-linear and dispersed from the line, suggesting diminished variability among the data. This phenomenon can be attributed to the substantial impact of flood damage, measured in Crore BDT per year, on Bangladesh's GDP over the years. Consequently, these variations in values have resulted in a significant deviation of most points

from the red line, i. The deviating data points also illustrate that the years in which Bangladesh saw more floods correspond to higher damage rates during those periods. A deeper analysis of the confidence intervals at levels α=0.90, 0.95, and 0.99 reveals that the lower percentage segment exhibits a stronger negative correlation, whereas the upper percentage segment of the significance level demonstrates a positive but nearly negligible correlation among the data points, thereby precluding any possibility of linear regression.

The residual analysis of the data was conducted, and a graphical representation was provided through linear regression of the residual and fitted values. The majority of the data points are dispersed, indicating a weak relationship among the variables. The Q-Q Residuals illustrate the relationship between standardized residuals and theoretical quantiles, with the majority of data points aligning along a single line, indicating a significant relationship among the data. A less significant relationship is observed in GDP scale location analysis, where a correlation exists between the root of standardized errors and fitted values. Although much of the data is scattered, some points align correctly, indicating a notable relationship to some extent.

IV. Discussion

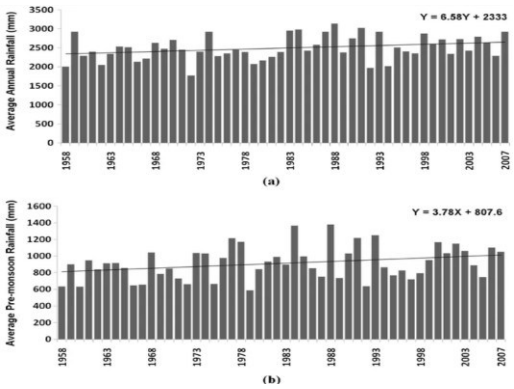

Fig. 3. Trends in **a** annual and **b** pre-monsoon rainfall of Bangladesh (averaged for nine stations) during the time period 1958–2007 [12]

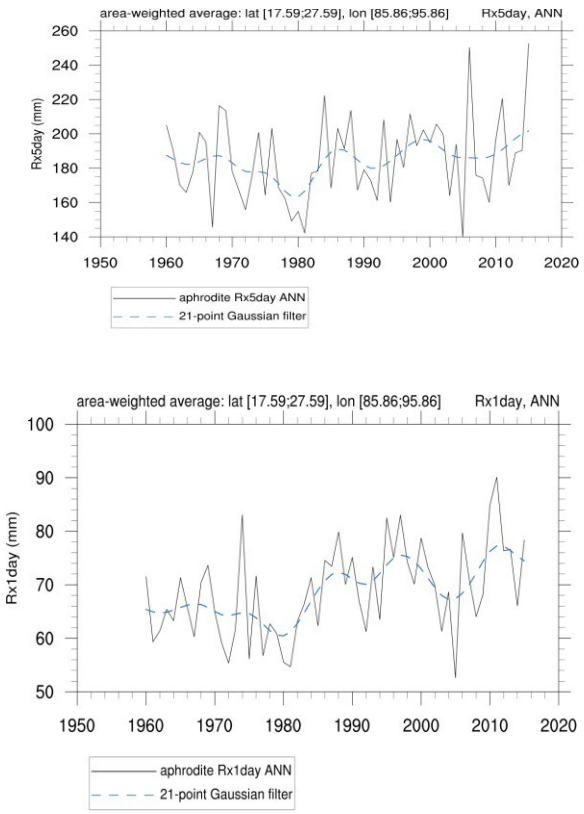

Fig. 4. Precipitation indices RX1day (the maximum daily precipitation) and RX5day (the maximum precipitation over *five consecutive days) of Bangladesh during the time period 1958 to 2016* [17]*[copyright www.climdex.org,2024-10-16; 10.1175/BAMS-D-11-00122.1]*

The precipitation data presented in figures (3, 4, 5) indicates a clear trend of increasing rainfall and a rising frequency of rainfall incidents in Bangladesh each year. Consequently, a swift increase in flood occurrences might be noted. However, it cannot yield any substantial analysis. Over the years, we have endeavored to establish a correlation between the damage inflicted by rainfall and flooding in Crores of GDP/BDT and the annual GDP in BDT (Bangladeshi Taka). A study of 30 years of data has been shown above. Through linear regression analysis, a viable visualization of the impact of flooding or excessive rainfall on GDP trends has been achieved.

Upon conducting a linear regression analysis of the parameters, a negative connection between them has been identified. However, this negative correlation does not indicate that the association is substantial. The lack of significance is attributed to the linear regression graph, where the line occasionally deviates from the data points. Analysis of the regression graph reveals that the fluctuating points, particularly in the years 1990, 1991, 1997, 2007, 2013, and 2016, correspond to significant cyclonic events. In 2007, a significant cyclone named Sidr occurred, followed by the Mahasen cyclone in 2013. In 2016, Cyclone Roanu

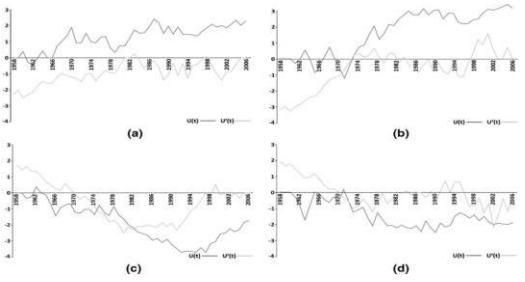

Fig. 5. ***a*** *annual heavy rainfall days (R20);* ***b*** *pre-monsoon heavy rainfall days (R20PrM);* ***c*** *continuous low rainfall days (CLRD); and* ***d*** *total number of pre-monsoon dry days (TDDPrM) of Bangladesh in a year from 1956 to 2006.*[12]

transpired. These severe cyclones inflicted substantial damage amounting to crores, consequently impacting the GDP of Bangladesh. In Bangladesh, the occurrence of cyclones or floods results in significant damage to infrastructure and livelihoods. The typical trend of GDP in our country is a year-on-year increase, accompanied by a corresponding reduction in damage control efforts, which do not remain consistent as GDP progresses annually. The damage control in BDT crores also increases beside the advancing GDP.

V. Conclusion

Bangladesh is susceptible to disasters. The reports indicate that Bangladesh is bordered by the Indian Ocean, with the Bay of Bengal region experiencing the highest frequency of cyclones. Bangladesh is a low-lying region, and hence, high rainfall increases the likelihood of flooding[18]. Additionally, during the monsoon season, water flows from India into Bangladesh, resulting in flooding of this low-lying area. In our rivers and estuaries, sedimentation is elevated, resulting in a reduction of the catchment area. As a result, adjacent land becomes inundated. Therefore, comprehensive attention to this country is essential for Bangladesh to defend itself or, at the very least, implement preventive measures against the ongoing climate change.

In a country like Bangladesh, statistical analysis indicates that we cannot use a framework due to the unique nature of its disasters. Moreover, abruptly constructing a dam and asserting that flooding will not occur in our country will also be ineffective. Instead, we will concentrate on developing climate resilience. Challenges will arise, but we will focus on how to swiftly address those challenges.

Bangladesh reads a far more volatile climate anomaly brought about due to global warming. Not possible for a developing country like Bangladesh, with the costs and technical complexity of replicating such large-scale infrastructure projects.

Instead, the country should prioritise enhancing its climate resilience through infrastructure plans that adapt to changing weather patterns and natural disasters; disaster preparedness measures; building flood- and cyclone-resistant communities.

The country should further raise its voice on climate diplomacy in the global arena. The country can mitigate the climate risks it highly exposed to; this risk is globally driven by environmental changes that would not under control of one single nation. Stronger advocacy for international cooperation and commitments to the reduction of greenhouse gas emissions will encourage similar actions in attempts to combat climate change on a global level, whilst standing as direct evidence required by Bangladesh, on an international grounding; thus, enabling it with equipped backing machinery essential towards advancing national adaptation strategies against its climatic doom. Bangladesh will engage in climate diplomacy — particularly with the big carbon emitter countries to make sure its voice is heard and it gets both financial and technical support necessary to shore up vulnerabilities.

References

[1] M. Dikici, "Drought analysis with different indices for the Asi Basin (Turkey)," *Sci. Rep.*, vol. 10, no. 1, p. 20739, Nov. 2020, doi: 10.1038/s41598-020-77827-z.

[2] Y. Lu *et al.*, "Spatial and Temporal Variability in Precipitation Concentration over Mainland China, 1961– 2017," *Water*, vol. 11, no. 5, Art. no. 5, May 2019, doi: 10.3390/w11050881.

[3] Y. Guan, F. Zheng, X. Zhang, and B. Wang, "Trends and variability of daily precipitation and extremes during 1960–2012 in the Yangtze River Basin, China," *Int. J. Climatol.*, vol. 37, no. 3, pp. 1282–1298, 2017, doi: 10.1002/joc.4776.

[4] W. Hu, J. Yao, Q. He, and J. Chen, "Changes in precipitation amounts and extremes across Xinjiang (northwest China) and their connection to climate indices," *PeerJ*, vol. 9, p. e10792, Jan. 2021, doi: 10.7717/peerj.10792.

[5] P. M. M. Soares, R. M. Cardoso, P. M. A. Miranda, P. Viterbo, and M. Belo-Pereira, "Assessment of the ENSEMBLES regional climate models in the representation of precipitation variability and extremes over Portugal," *J. Geophys. Res. Atmospheres*, vol. 117, no. D7, 2012, doi: 10.1029/2011JD016768.

[6] E. J. Powell and B. D. Keim, "Trends in Daily Temperature and Precipitation Extremes for the Southeastern United States: 1948–2012," Feb. 2015, doi: 10.1175/JCLI-D- 14-00410.1.

[7] Y. Wang, Z. Peng, H. Wu, and P. Wang, "Spatiotemporal Variability in Precipitation Extremes in the

Jianghuai Region of China and the Analysis of Its Circulation Features," *Sustainability*, vol. 14, no. 11, Art. no. 11, Jan. 2022, doi: 10.3390/su14116680.

[8] A. R. Md. T. Islam *et al.*, "Spatiotemporal distribution of drought and its possible associations with ENSO indices in Bangladesh," *Arab. J. Geosci.*, vol. 14, no. 23, p. 2681, Nov. 2021, doi: 10.1007/s12517-021-08849-8.

[9] L. Tian, Z. Leasor, and S. M. Quiring, "Potential to improve precipitation forecasts in Texas through the incorporation of multiple teleconnections," *Int. J. Climatol.*, vol. 37, no. 10, pp. 3863–3872, 2017, doi: 10.1002/joc.4960.

[10] "Regional changes of precipitation and temperature over Bangladesh using bias-corrected multi-model ensemble projections considering high-emission pathways - Fahad - 2018 - International Journal of Climatology - Wiley Online Library." Accessed: Oct. 21, 2024. [Online]. Available: https://rmets.onlinelibrary.wiley.com/doi/10.1002/joc.5284

[11] N. Endo *et al.*, "Trends in Precipitation Characteristics in Bangladesh from 1950 to 2008," *Sola*, vol. 11, pp. 113–117, 2015, doi: 10.2151/sola.2015-027.

[12] S. Shahid, "Trends in extreme rainfall events of Bangladesh," *Theor. Appl. Climatol.*, vol. 104, no. 3, pp. 489– 499, Jun. 2011, doi: 10.1007/s00704-010-0363-y.

[13] "World Development Indicators | DataBank." Accessed: Jul. 09, 2024. [Online]. Available: https://databank.worldbank.org/source/world-development- indicators

[14] "Democratic Republic of the Congo vs Luxembourg Economy Stats Compared." Accessed: Oct. 22, 2024. [Online]. Available: https://www.nationmaster.com/country-info/compare/Democratic-Republic-of-the-

[15] "Delta Plan 2100." Accessed: Oct. 18, 2024. [Online]. Available: https://bdp2100kp.gov.bd/

[16] A. R. Kamel and M. R. Abonazel, "A Simple Introduction to Regression Modeling using R," *Comput. J. Math. Stat. Sci.*, Apr. 2023, doi: 10.21608/cjmss.2023.189834.1002.

[17] A. Yatagai, K. Kamiguchi, O. Arakawa, A. Hamada, N. Yasutomi, and A. Kitoh, "APHRODITE: Constructing a Long-Term Daily Gridded Precipitation Dataset for Asia Based on a Dense Network of Rain Gauges," *Bull. Am. Meteorol. Soc.*, vol. 93, no. 9, pp. 1401–1415, Sep. 2012, doi: 10.1175/BAMS-D-11-00122.1.

[18] A. Y. Md. Abdullah, Md. H. Bhuian, G. Kiselev, A. Dewan, Q. K. Hassan, and M. Rafiuddin, "Extreme temperature and rainfall events in Bangladesh: A comparison between coastal and inland areas," *Int. J. Climatol.*, vol. 42, no. 6, pp. 3253–3273, 2022, doi: 10.1002/joc.6911.

Cluster Analysis of Microbial, Physico-Chemical Characteristics, Water Quality Index (WQI) and Trophic Level Index (TLI) for Water Quality Assessment of Beira Lake, Colombo, Sri Lanka

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***Abstract*— This study investigates the water quality and microbial diversity of Beira Lake, Colombo, by analyzing comprehensive physico-chemical parameters and microbial characteristics. Twenty sampling locations were assessed using the Water Quality Index (WQI) and Trophic Level Index (TLI). A key aspect of this research is the use of cluster analysis to group sampling locations based on similarities in microbial communities and water quality parameters. This analysis identified distinct clusters within Beira Lake, highlighting regions with varying pollution levels and microbial diversity. The identification of pollution hotspots, along with the grouping of areas with similar environmental conditions, provides valuable insights into the spatial distribution of water quality issues across the lake. These clusters largely corresponded to surrounding land-use patterns. Notably, highly polluted outliers (L14, L15, and L18) aligned with known issues such as unauthorized sewer lines, stagnant water, and urban waste sources. The study emphasizes the urgent need for comprehensive pollution mitigation measures to improve water quality and restore the ecological balance of Beira Lake. Immediate interventions targeting both point and non-point source pollution are crucial to addressing the significant environmental stress on the lake. The findings offer critical insights into lake management efforts, underscoring the need for targeted conservation strategies to address pollution sources and enhance water quality.**

Keywords*— *Beira Lake, water quality assessment, microbial diversity, Water Quality Index (WQI), Trophic Level Index (TLI), cluster analysis

I. Introduction

Beira Lake, located at the heart of Colombo, Sri Lanka, is a man-made water body with a rich historical and ecological significance. Originally constructed by the Portuguese in 1551 for military defense, the lake has since evolved into a vital ecological resource for the city. It plays a crucial role in flood regulation, acts as a habitat and nesting ground for a variety of urban wildlife, and contributes to groundwater recharge. In addition, it serves as a recreational spot and a key landmark, enhancing the urban landscape. However, Beira Lake is under significant environmental pressure due to rapid urbanization and industrial activities within its catchment area. Untreated sewage, industrial waste, and stormwater runoff have led to elevated levels of pollutants, threatening the lake's ecosystem. This degradation not only disrupts water quality but also impacts the microbial communities, which are essential for maintaining ecological balance. The lake's eutrophication, indicated by algal blooms and decreasing water quality, further emphasizes the urgent need for intervention.

This research sought to assess the status of Beira Lake by analyzing both its microbial characteristics and physico-chemical properties. Using a combination of the Water Quality Index (WQI) and Trophic Level Index (TLI), this study provided an in-depth evaluation of the lake's ecological health. Moreover, through cluster analysis, the sampling locations were grouped based on their similarities in water quality parameters and microbial diversity. This allowed for a detailed understanding of pollution sources and the identification of distinct ecological zones within the lake. The findings will inform future lake management and conservation strategies, aiming to restore and preserve the ecological integrity of Beira Lake.

II. Materials and Methods

Description of the study sites

This study was conducted in Beira Lake, Colombo, Sri Lanka, which has a maximum depth of 5.6 meters and holds approximately 2,903,000 cubic meters of water. The research focused on four main basins: East Lake, Galle Face Lake, West Lake, and Southwest Lake. To comprehensively assess the water quality of Beira Lake, twenty surface sampling locations were carefully selected to cover the lake's basins, inlets, outlets, and known pollution hotspots. This selection was informed by historical water quality data from the Sri Lanka Land Development Corporation (SLLDC), which has been monitoring thirty-two sites across Beira Lake since 2019. These locations were originally chosen to represent the lake's pollution levels and capture significant inflows and outflows. For this study, the final twenty sampling sites were selected based on the water quality measurements conducted by the SLLDC in 2023 (confidential data). Key parameters influencing the selection included temperature, pH, electrical conductivity (EC), salinity, total dissolved solids (TDS), dissolved oxygen (DO), ammonia, nitrate, phosphate, biological

oxygen demand over five days at 20°C (BOD5), and chemical oxygen demand (COD). This approach ensured that the chosen sites were geographically diverse and representative of the lake's varying environmental conditions and pollution levels. Detailed GPS coordinates and information for each sampling location are provided in Table I and illustrated in Figure 1.

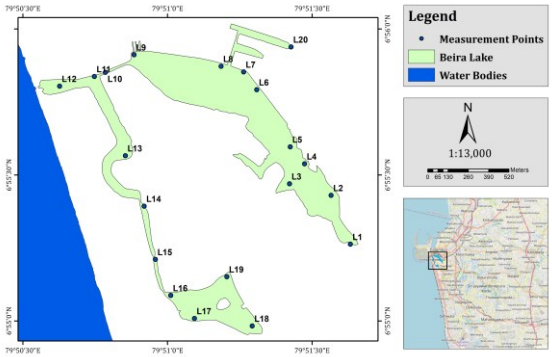

Fig. 1. Locations of surface sampling stations of study area

DETAILS ON LATITUDE, LONGITUDE OF SAMPLING LOCATIONS OF STUDY AREA

ID	Latitude	Longitude	ID	Latitude	Longitude
L1	6.93186	79.848068	L11	6.9261	79.847565
L2	6.931202	79.85308	L12	6.92322	79.848647
L3	6.929862	79.855135	L13	6.92018	79.849293
L4	6.926602	79.857063	L14	6.91919	79.853413
L5	6.921046667	79.860527	L15	6.91681	79.851547
L6	6.924497	79.857022	L16	6.916383	79.854872
L7	6.923996667	79.85852167	L17	6.918125	79.850182
L8	6.925633	79.85789167	L18	6.93033	79.85050667
L9	6.930616667	79.84578	L19	6.923837	79.859418
L10	6.930065	79.84377667	L20	6.9323055	79.85711117

1. Sample collection and laboratory analysis

Sample Collection: Water samples were collected in sterile containers between January and March 2024, following preservation protocols to ensure microbiological integrity.

Physico-chemical Parameters: In-situ measurements, including temperature, pH, electrical conductivity (EC), salinity, total dissolved solids (TDS), and dissolved oxygen (DO), were taken using a calibrated multiparameter probe, while water clarity was measured with a Secchi disc. Ex-situ analyses of parameters such as chemical oxygen demand (COD), biological oxygen demand (BOD), ammonia, nitrate, phosphate, and total organic matter were performed using standard procedures, including the APHA 5220 B method for COD and a Palintest 7100® photometer for nutrient analysis.

Microbial Parameters: The diversity and density of cyanobacteria, diatoms, zooplankton, and aerobic bacteria were assessed using light microscopy and standard protocols. Fecal coliform and Escherichia coli (E. coli) levels were determined following ISO 9308-2:1990 standards, while chlorophyll-a content was measured using spectrophotometry.

Water Quality Index (WQI): The overall water quality of Beira Lake was assessed using the WQI method, which consolidates multiple water quality indicators into a single dimensionless value. The WQI model developed by Uddin et al. (2021) was applied to the 20 sampling stations across Beira Lake's basins (East, West, Southwest, and Galle Face). The parameters selected for the WQI calculation included biological oxygen demand (BOD), chemical oxygen demand (COD), dissolved oxygen (DO), nitrate, phosphate, ammonia, and pH. These parameters were chosen to provide a holistic view of both the physicochemical and microbial conditions of the lake.

The WQI was calculated by converting the measured concentrations of these parameters into dimensionless sub-indices based on guidelines from the Central Environment Authority (CEA) of Sri Lanka. Sub-indices were directly derived from measured values, with ammonia categorized according to Category C standards for aquatic life. A weighted average method was used to compute the final WQI score.

All equations related to this calculation are given below, numbered from 1 to 4.

$$Q_n = \frac{V_n - V_i}{S_n - V_i} \quad (1)$$

$$K = \frac{1}{\left(\frac{1}{\sum_{i=1}^{n} S_n}\right)} \quad (2)$$

$$W_n = \frac{K}{S_n} \quad (3)$$

$$WQI = \frac{\sum W_n \times Q_n}{\sum W_n} \quad (4)$$

Were,

- Vn = the estimated value of the nth parameter of the considered sampling station
- Vi = the ideal value of nth parameter in pure water
- Sn = the standard permissible value for nth parameter specified by CEA
- Qn = the quality rating for nth parameter,
- K = the proportionality constant
- Wn = the Unit weight for nth parameter
- WQI = Water Quality Index value for the sampling station

The calculated WQI values were categorized as shown below:

- WQI 0-25: Excellent (Class A)
- WQI 26-50: Good (Class B)
- WQI 51-75: Poor (Class C)
- WQI 76-100: Very Poor (Class D)
- WQI >100: Unfit for Consumption (Class E)

Trophic Level Index (TLI): TLI was calculated to evaluate the eutrophication status of Beira Lake. Key parameters used in the TLI calculation included chlorophyll-a concentration, Secchi disc depth, total phosphorus, and total nitrogen. These parameters were combined to generate a TLI score, which reflects nutrient levels and their influence on the lake's ecosystem, providing an overall assessment of the lake's trophic state.

The TLI was calculated using the following formulas, numbered 5 to 9.

$$TLI = \frac{\{TL(Chl-a) + TL(SD) + TL(TP) + TL(TN)\}}{4} \quad (5)$$

Where:

- TL(Chl−a) = Trophic Level for Chl-a concentration

$$TL(Chl-a) = 2.22 + 2.54 \log(Chl-a) \quad (6)$$

- TL(TP) = Trophic Level for Total phosphorus

$$TL(TP) = 0.218 + 2.92 \log(TP) \quad (7)$$

- TL(TN) = Trophic Level for Total nitrogen

$$TL(TN) = -3.61 + 3.01 \log(TN) \quad (8)$$

- TL(SD) = Trophic Level for Secchi disc depth

$$TL(SD) = 5.10 + 2.60 \log(1/SD - 1/40) \quad (9)$$

The TLI values were categorized as shown below:

- Ultra-microtrophic: Trophic Level < 1
- Microtrophic: Trophic Level 1 - 2
- Oligotrophic: Trophic Level 2 - 3
- Mesotrophic: Trophic Level 3 - 4
- Eutrophic: Trophic Level 4 - 5
- Supertrophic: Trophic Level 5 - 6
- Hypertrophic: Trophic Level > 6

This approach to WQI and TLI helps assess both water quality and nutrient levels, providing insight into Beira Lake's ecological health and its impact on microbial communities.

2. *Data analysis*

Statistical analysis: Several statistical methods were used to analyze the collected data. A Pearson correlation coefficient was applied to identify relationships among all measured variables and between the two water quality indices, with a significance level of $\alpha = 0.05$. Fecal coliform and E. coli densities were categorized, and Analysis of Variance (ANOVA) was conducted to determine if there were significant differences between categories for each biological parameter. Tukey's HSD method was used to identify significant pairs of means. Multiple linear regression analysis was performed to model the relationships between microbiological parameters and physicochemical variables, using stepwise selection to identify significant predictors. Additionally, ordinal logistic regression was applied to explore how physical and chemical parameters impact the categorized densities of fecal coliform and E. coli. All statistical analyses were conducted using SPSS (Statistical Package for Social Science).

III. Result and Discussion

Status of Surface Water Quality of Beira Lake

The assessment of surface water quality in Beira Lake provides essential insights into its ecological health, as illustrated in Table II, which presents a statistical summary of the tested parameters. This comprehensive analysis covers a range of physico-chemical and microbial characteristics, WQI and TLI. The statistical data reveal significant variations, with minimum, maximum, mean values, and standard deviations for each parameter. These results highlight the complex interactions within the lake's ecosystem and underline the necessity for effective management strategies to mitigate pollution and restore the ecological balance of Beira Lake.

Statistical summary of Beira Lake Tested parameters

Parameters	Min	Max	Mean	Standard Deviation
pH	9.30	10.90	10.02	0.104
Temperature (°C)	29.70	32.40	31.21	0.770
TDS (mg/l)	108.00	241.00	157.10	29.790
EC (µs/cm)	282.00	491.00	321.30	55.490
Salinity (%)	0.13	0.25	0.15	0.030
Phosphate (mg/L)	0.46	3.40	1.54	0.970
Nitrate (mg/L)	0.07	0.18	0.12	0.030
Ammonia (mg/L)	0.60	10.80	3.36	3.140
DO (mg/L)	10.57	21.67	17.01	3.390
COD (mg/L)	27.00	345.00	79.90	67.700
BOD (mg/L)	40.00	252.00	93.80	67.030
Secchi Depth (m)	0.01	0.24	0.16	0.080
Organic Carbon in sediment % (w/w)	0.29	22.23	10.68	5.850
Spirulina Sp. (cells/ mL)	0.00	9373.33	3811.17	3578.830
Microcystis Sp. (cells/ mL)	208.33	6918.33	1283.42	1907.080
Anabaena (cells/ mL)	0.00	43.33	10.83	13.330
Planktothrix agardhii (cells/ mL)	0.00	61.67	34.17	18.110
Chlorophyll -a (µg/L)	105.64	1330.81	343.09	313.380
Aerobic Plate Count (log (CFU/mL))	3.15	7.38	4.92	4.820
WQI	183.69	1538.67	464.98	302.110
TLI	6.23	7.86	6.90	0.490

3. *Principal component analysis*

All the measured variables and the estimated quality indices were standardized before the principal component analysis. The objective of the standardization of the data was to convert the data in different units and scales into the same scale and unitless. Principle component analysis was done to find the suitable principal components that are used to cluster analysis. Principle component analysis has selected six principal components to represent the variability of the tested data set. Selection of the suitable principal components done by eigen value of the components and the selected principal six components had eigen values higher than 1. Those six principal components had been expressed the 83.52% of the total variability of the total data set. (Figure 2, Table III)

Principal Component Analysis: Extraction Sums of Squared Loadings

Component	Extraction Sums of Squared Loadings	
	% of Variance	Cumulative %
1	30.30	30.30
2	16.52	46.82
3	13.70	60.52
4	10.54	71.06
5	6.44	77.50
6	6.02	83.52

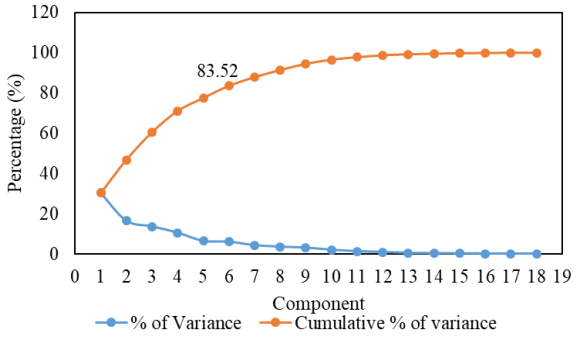

Fig. 2. *Scree Plot of Principal Component Analysis (PCA)*

4. *Canonical discriminant analysis*

The agglomerative hierarchical cluster analysis methods were followed at the beginning. Among them, ward's linkage method had given the better classification for the tested locations, based on the used six principal components. classification of the locations by ward method has depicted in the following dendrogram (Figure 3). According to dendrogram of ward linkage method, seven clusters have been identified.

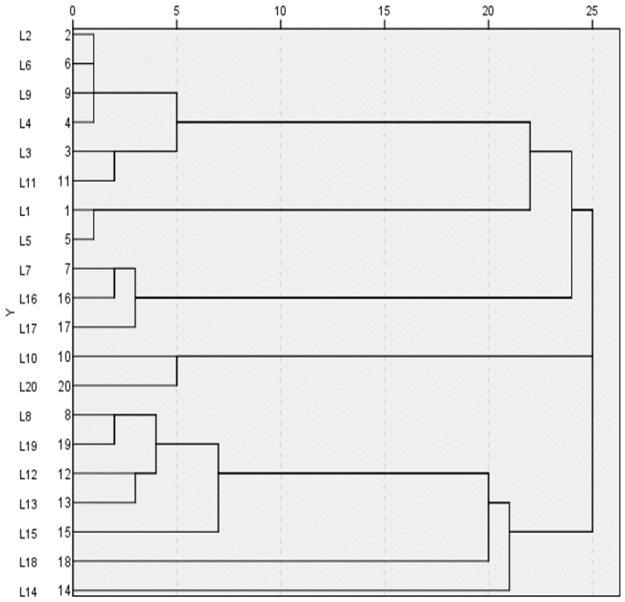

Fig. 3. *Dendrogram of locations from cluster analysis using Ward Linkage method*

K-Means clustering is a partitioning method of clustering. Twenty locations were also classified using the K-Means clustering method. Seven clusters were predetermined for the analysis, based on Ward's method.

Table IV below shows the clusters and the distance of each location from its respective centroid. The clusters obtained from the K-Means method yielded the same results as those from the Ward clustering method.

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CLUSTERS AND THE DISTANCE FROM THE CENTROID OF EACH LOCATION

ID	Cluster	Distance	ID	Cluster	Distance
L1	5	0.510	L11	4	0.996
L2	4	0.488	L12	2	1.488
L3	4	1.322	L13	2	1.270
L4	4	0.832	L14	3	0.000
L5	5	0.510	L15	2	2.015
L6	4	0.659	L16	7	1.174
L7	7	0.721	L17	7	1.194
L8	2	1.171	L18	6	0.000
L9	4	0.706	L19	2	1.154
L10	1	1.209	L20	1	1.209

Among above mentioned 20 locations (L1 – L20) 14th (L14) and 18th (L18) location selected as separate clusters. Also, 15th (L15) had shown considerable distance from the cluster centroid. Therefore, other seventeen locations out of twenty had divided into five cluster as follows. ((Table V)

CLUSTERING RESULTS - DISTRIBUTION OF SAMPLING LOCATIONS

Cluster_1	Cluster_2	Cluster_3	Cluster_4	Cluster_5
L2	L1	L7	L10	L8
L3	L5	L16	L20	L12
L4		L17		L13
L6				L19
L9				
L11				

5. *Canonical discriminant analysis*

The Canonical discriminant analysis is the validation method of new clusters. As the first step, the multivariate analysis of variance test was used to determine whether there are significant differences among clusters based on the tested principal components. According to analysis, wilk's lambda value was less than 0.0001 (1st degree of freedom (DF_1) = 6, DF_2 = 6, and DF_3 = 13) and the approximate F value was 13.156 (DF_1=36, DF_2=37.9). The probability of those two statistics was less than 0.0001. Therefore, there should be significant differences among clusters. F test was used to identify the pair-wise differences among clusters. The significance of the differences was determined at 0.05 critical probability level. The following table shows that all the probability values of the F values are less than 0.05. Therefore, all the clusters had been significantly ($P<0.05$) separated from each other by the cluster analysis.

6. *Determination of variability among location clusters*

Analysis of Variance (ANOVA) test was used to find whether there are significant differences among clusters in each measured parameters and estimated indices. Univariate ANOVA tests results have given below table VI. The Phosphate content, the Bio-chemical oxygen demand, and the Secchi depth had shown significant ($P<0.05$) differences among cluster means. Among biological parameters, significant ($P<0.05$) differences between cluster means had found in the chlorophyll-a content, the cell count of Spirulina Species, and the cell count of *Microcystis* Species. Also, the WQI and the TLI had expressed the significant ($P<0.05$) differences among cluster means.

ANOVA TESTS RESULTS OF THE TESTED PARAMETERS

Parameter	F value	Probability	Conclusion
pH	2.910	0.068	Not significant
Phosphate (mg/L)	34.387	0.000	Significant
Nitrate (mg/L)	2.797	0.075	Not significant
Ammonia (mg/L)	2.633	0.087	Not significant
DO (mg/L)	2.313	0.117	Not significant
COD (mg/L)	1.419	0.286	Not significant
BOD (mg/L)	7.795	0.002	Significant
Organic Carbon in sediment (% by mass)	1.066	0.415	Not significant
Temperature (°C)	1.092	0.404	Not significant
Secchi Depth (m)	16.466	0.000	Significant
TDS (mg/l)	1.220	0.353	Not significant
Electrical Conductivity (µs/cm)	1.454	0.276	Not significant
Salinity (%)	2.122	0.141	Not significant
Chlorophyll -a (µg/L)	32.411	0.000	Significant
Aerobic Plate Count (log (CFU/mL))	0.932	0.478	Not significant
Spirulina Sp. (cells/mL)	8.077	0.002	Significant
Microcystis Sp. (cells/mL)	25.824	0.000	Significant
Anabaena (cells/mL)	0.409	0.799	Not significant
Planktothrix agardhii (cells/mL)	1.136	0.386	Not significant
WQI	4.787	0.015	Significant
TLI	15.354	0.000	Significant

7. *Duncan Multiple Range Test*

The Duncan Multiple Range Test (DMRT) was used to identify significantly different pairs of means. According to the Duncan grouping, the 4th cluster had the highest phosphate content compared to the other clusters. Additionally, the mean phosphate content of the 2nd cluster was significantly lower than that of the 3rd cluster. DMRT analysis of BOD content revealed that the 5th cluster had the highest BOD content, while the mean BOD contents of the other clusters were not significantly different from each other. Secchi depth, a physical parameter, showed significant differences among the clusters. Based on Duncan grouping, the mean Secchi depth of the 5th cluster was the lowest among the clusters, while the other four clusters did not show any significant differences in Secchi depth.

Regarding chlorophyll-a content, the 5th cluster had the significantly highest mean, while the other four clusters did not show any significant differences in chlorophyll-a content. Among the tested microbes, the mean densities of Spirulina and Microcystis species showed significant differences across clusters. The 1st, 2nd, and 5th clusters had higher mean densities of Spirulina species than the other clusters, although the mean densities within these three clusters were not significantly different from each other. Similarly, the mean densities of Spirulina species in the 3rd and 4th clusters were not significantly different. For Microcystis species, the 3rd cluster had the highest mean density, while the mean cell counts per mL in the other four clusters did not show any significant differences.

The Water Quality Index (WQI) and Trophic Level Index (TLI) were estimated based on the measured parameters to describe the varying cumulative conditions in Beira Lake. The WQI yielded interesting results in relation to the clusters: the means of the 5th and 4th clusters were higher than those of the 1st and 2nd clusters, while the mean of the 3rd cluster did not show any significant difference compared to the other clusters. The results for the TLI were also intriguing. The 5th cluster had the highest TLI mean among all clusters, while the 4th cluster had a higher mean TLI than the 1st, 2nd, and 3rd clusters, which did not differ significantly from each other.

The following graphs (4–11) illustrate the significant differences among cluster means for each significant parameter.

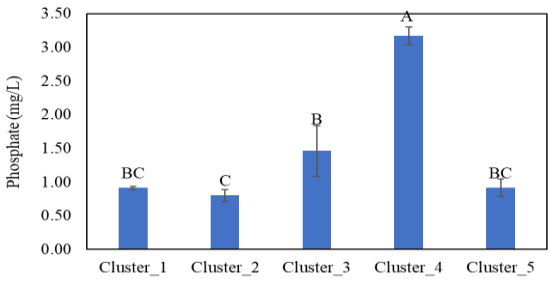

Fig. 4. Comparison of phosphate levels across clusters

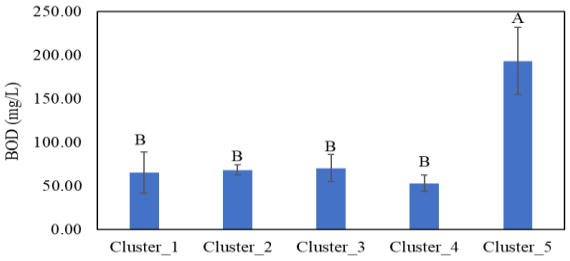

Fig. 5. Comparison of BOD levels across clusters

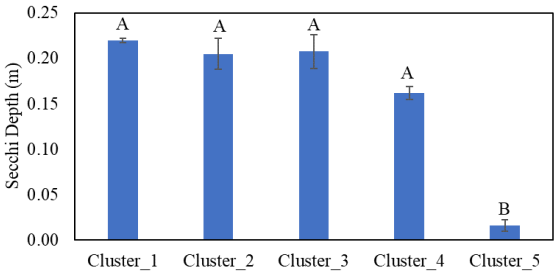

Fig. 6. Comparison of secchi depth levels across clusters

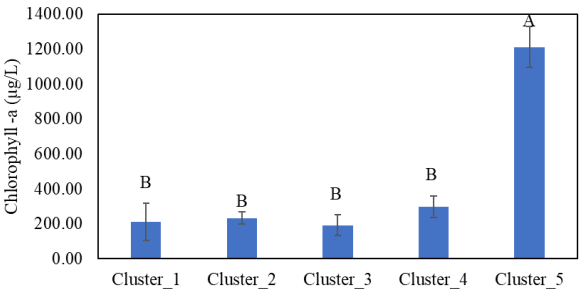

Fig. 7. Comparison of chlorophyll -a levels across clusters

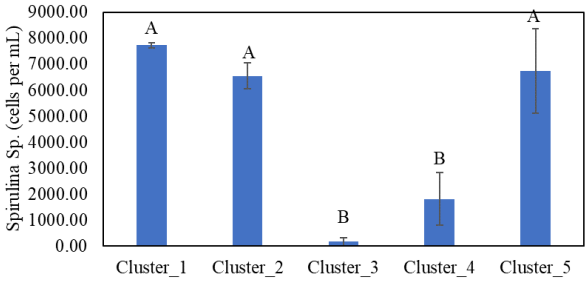

Fig. 8. Comparison of *Spirulina Sp*. levels across clusters

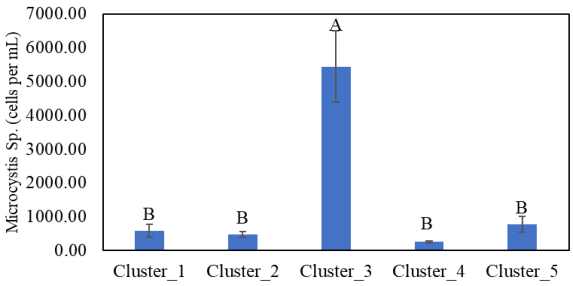

Fig. 9. Comparison of *Microcystis Sp*. levels across clusters

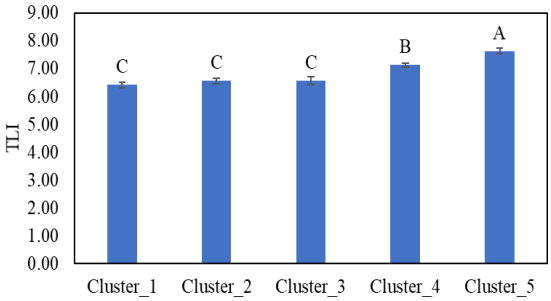

Fig. 10. Comparison of TLI values across clusters

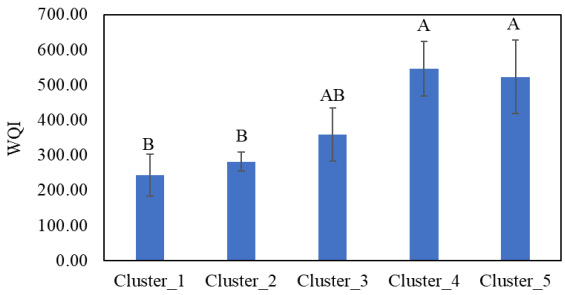

Fig. 11. Comparison of WQI values across clusters

8. *Extreme locations*

Beira L14, L15, and L18 were excluded from the ANOVA because they were identified as outliers based on cluster analysis. By comparing the values of the measured or estimated parameters for these locations with the 95% confidence interval of each parameter, the following conclusions were drawn: For L14, the values of 15 out of 20 parameters fell outside the 95% confidence interval. Similarly, L15 and L18 had 12 and 11 parameters, respectively, outside the 95% confidence interval. Consequently, L14, L15, and L18 were grouped into three distinct clusters, likely due to the reasons. Table VII presents the mean values of the clusters and the values for L14, L15, and L18 in parameters where their values were higher than the highest cluster mean and/or lower than the lowest cluster mean.

According to the table, L14 recorded values for both pH and Spirulina sp. density that were lower than the lowest cluster means. Additionally, L14 exhibited higher values than the highest cluster means for 12 parameters, including WQI and TLI. In L15, three parameters, including WQI, had values higher than the highest cluster means, while five parameters showed lower values than the lowest cluster means. The TLI value for L15 was lower than that of the fifth cluster, which had the highest means. At L18, eight parameters, including WQI, had values higher than the highest cluster means, while ammonia content, total dissolved solids, and Spirulina sp. density were lower than the lowest cluster means for these parameters. The TLI value for L18 was higher than that of the first three clusters, which had the lowest TLI means. For the parameters that showed significant results beyond WQI and TLI, both L15 and L18 exhibited higher BOD values than all cluster means, while L14 had a lower BOD value than all clusters. Furthermore, in all three locations (L14, L15, and L18), Spirulina sp. densities were lower than all cluster means, whereas *Microcystis sp.* densities were higher than all cluster means.

COMPARISON OF PARAMETER VALUES FOR EXTREME LOCATIONS WITH CLUSTER MEANS

Parameter	Cluster No.					L14	L15	L18
	1	2	3	4	5			
pH	10.35	9.93	10.33	9.60	10.25	9.30	10.00	10.90
Nitrate (mg/L)	0.09	0.13	0.10	0.13	0.10	0.18	0.07	0.07
Ammonia (mg/L)	1.15	2.27	6.33	3.07	1.75	10.80	0.80	1.60
DO (mg/L)	12.08	18.01	19.69	18.00	16.64	11.28	14.75	17.60
COD (mg/L)	34.50	55.83	65.33	71.50	89.50	345.00	96.00	92.00
BOD (mg/L)	65.50	68.50	70.67	53.25	193.50	58.00	212.00	252.00
TDS (mg/l)	148.50	144.50	155.00	166.00	176.00	241.00	148.00	108.00
EC (µs/cm)	296.50	288.83	309.67	337.00	349.00	491.00	298.00	336.00
Salinity (%)	0.14	0.13	0.14	0.17	0.17	0.25	0.14	0.16
APC (log (CFU/mL)	4.83	5.11	4.62	4.20	5.23	5.32	4.36	7.38
Spirulina sp. (cells/mL)	7732.50	6551.94	168.33	1817.92	6741.67	161.67	25.00	0.00
Microcystis sp. (cells/mL)	580.83	476.67	5443.33	261.25	780.83	905.00	756.67	1048.33
Anabaena (cells/mL)	12.50	8.61	1.67	14.58	13.33	28.33	0.00	21.67
Planktothrix agardhii (cells/mL)	37.50	41.39	31.11	19.17	40.00	41.67	8.33	60.00
WQI	243.06	282.24	358.38	546.48	523.31	1538.67	621.04	652.62
TLI	6.42	6.57	6.56	7.13	7.64	7.86	7.49	6.83

9. *Cluster Analysis Results and Land Use Patterns*

Cluster analysis have identified five statistically significant clusters (Clusters 1-5) for water quality parameters across 17 locations in Beira Lake, excluding outliers which are L14, L15, and L18. Here, we examine how these clusters align with the land use patterns of the corresponding locations.

Cluster 1 - All locations in this cluster are situated within the East Beira Lake basin. While L9 is located near the outflow point to the ocean, the large volume of East Beira Lake allows for some dilution of pollutants. However, L4's proximity to Norris Canal necessitates further investigation of catchment through the canal due to potential sewage connections. Although these locations are clustered together statistically, the pollution levels based on land use patterns may vary, indicating a need for further study of canal catchments.

Cluster 2 - L1 has mostly stagnant water with high siltation, suggesting lower pollution from surrounding areas. L5, near Norris Canal, receives high pollution from the National Hospital waste. However, the high-water volume in L5's area allows for some dilution. While statistically clustered together, further study of the canal's catchment area is recommended to definitively assess pollution levels.

Cluster 3 - L7, located near L8, might receive diluted water. L16 and L17 are in Southwest Beira, with stagnant water in L14 and L15 (outliers) limiting flow from those areas. Pollution from shanties, wastewater inlets, and sewers at L18 and L19 could potentially spread to L16 and L17. Despite being statistically grouped, land use patterns suggest potential variations in pollution levels, necessitating a study of canal catchments.

Cluster 4 - L10 acts as a convergence point for pollutants in East Beira Lake before they flow out through a narrow channel. L20, near the Floating Market, receives pollutants from St. Sebastian canal. The similarity in pollution sources suggests these locations might have comparable water quality, justifying their inclusion in the same cluster.

Cluster 5 - L8 is a convergence point for pollutants from the Floating Market and finger section of Beira Lake. The flow towards East Beira Lake might lead to some dilution. L12 experiences increased pollution due to Beira Lake's outflow into the Indian Ocean through a semi-circular spillway. L13 receives water from highly polluted locations (L14, L15) and L10. L19 is influenced by pollution from Navam Mawatha, including Navaloka Hospital. Although statistically clustered, land use patterns suggest varying pollution levels, indicating a need for further investigation of catchment areas through canals.

Outliers - The identification of L14, L15, and L18 as separate clusters aligns with their land use patterns, known to be the most polluted areas in Beira Lake. These locations have a restricted water volume, minimal dilution, and confirmed sources of high pollution (unauthorized sewer lines, stagnant water). Similarly, L18 in Southwest Beira receives a high volume of urban waste from various sources. Therefore, the separate clustering of these locations statistically reflects the land use patterns and reinforces their designation as outliers.

The cluster analysis identified statistically significant groupings that generally correspond to the land use patterns of the respective locations. However, due to the complexity of water flow and potential influences from upstream catchments, further investigation of canal systems is necessary for a more definitive understanding of pollution dynamics within Beira Lake.

IV. Conclusion and Recommendations

The cluster analysis done in the study has identified significant groupings of sampling locations in Beira Lake based on physicochemical and biological parameters, which correlated with land use patterns and pollution sources. The analysis revealed highly polluted outliers (L14, L15, and L18), emphasizing the detrimental effects of unauthorized sewer lines, stagnant water, and urban waste on these areas. The findings indicate a severe water quality crisis, driven by both point-source and non-point-source pollution, underscoring the urgent need for robust interventions. Immediate actions, such as controlling wastewater discharge and improving sanitation infrastructure, are crucial for restoring the lake's ecological health and ensuring its sustainability.

To enhance the restoration and management of Beira Lake, several recommendations are proposed. Increasing the number of sampling locations and considering multi-depth sampling will improve data accuracy and understanding of pollution distribution. Treatment efforts should prioritize stagnant areas by implementing aeration systems and nature-based solutions like floating wetlands, which can enhance water quality and aesthetics. Regular solid waste management, along with identifying pollution sources, is vital for addressing contamination. Enforcing environmental regulations, disconnecting unauthorized sewer lines, and reducing phosphorus loading will further aid in mitigating pollution. By focusing on these strategies, significant progress can be made toward restoring Beira Lake's ecological health for the benefit of both the local community and the ecosystem.

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References

[1] D. R. Pearsall et al., “Environmental Reviews and Case Studies: ‘Make No Little Plans’: Developing Biodiversity Conservation Strategies for the Great Lakes,” Environ. Pract., vol. 15, no. 4, pp. 462–480, 2013, doi: 10.1017/s1466046613000410.

[2] W. H. Sugiharto, M. I. Ghozali, S. Suryono, H. Susanto, and M. A. Budihardjo, “Online monitoring of water pollution level based on dissolved oxygen (DO) and biochemical oxygen demand (BOD) using wireless sensor system,” J. Phys. Conf. Ser., vol. 1943, no. 1, 2021, doi: 10.1088/1742-6596/1943/1/012016.

[3] X. David and E. Daniel, “Article (refereed) - postprint,” 2020.

[4] M. Fiello, A. T. Mikell, M. T. Moore, and C. M. Cooper, “Variability in the characterization of total coliforms, fecal coliforms and Escherichia coli in recreational water supplies of North Mississippi, USA,” Bull. Environ. Contam. Toxicol., vol. 93, no. 2, pp. 133–137, 2014, doi: 10.1007/s00128-014-1299-1.

[5] X. Zhang et al., “Characteristic analysis of phospholipid fatty acids (PLFAs) in typical nutrient polluted lake sediment in Wuhan,” Int. J. Sediment Res., vol. 36, no. 2, pp. 221–228, 2021, doi: 10.1016/j.ijsrc.2020.09.002.

[6] E. Jaiani et al., “Microbial water quality of recreational lakes near Tbilisi, Georgia,” J. Water Health, vol. 11, no. 2, pp. 333–345, 2013, doi: 10.2166/wh.2013.057.

[7] [9] A. E. Barbosa, “Analysis of Methodologies for Assessment of Urban Drainage Impacts in Lakes and Reservoirs,” Open Environ. Biol. Monit. J., vol. 5, no. 1, pp. 30–38, 2013, doi: 10.2174/1875040001205010030.

[8] A. H. M. J. Alobaidy, H. S. Abid, and B. K. Maulood, “Application of Water Quality Index for Assessment of Dokan Lake Ecosystem, Kurdistan Region, Iraq,” J. Water Resour. Prot., vol. 02, no. 09, pp. 792–798, 2010, doi: 10.4236/jwarp.2010.29093.

[9] T. Miller et al., “Predictive Modeling of Urban Lake Water Quality Using Machine Learning: A 20-Year Study,” Appl. Sci., vol. 13, no. 20, p. 11217, 2023, doi: 10.3390/app132011217.

[10] W. Q. Assessment and D. Indices, “of Agricultural Sciences Water Quality Assessment and Eutrophic Classification of Hanoi Lakes Using,” vol. 4, no. 4, pp. 1229–1240, 2021.

[11] A. N. Al-Ghadban, P. G. Jacob, and F. Abdali, “Total organic carbon in the sediments of the Arabian Gulf and need for biological productivity investigations,” Mar. Pollut. Bull., vol. 28, no. 6, pp. 356–362, 1994, doi: 10.1016/0025-326X(94)90272-0.

[12] T. Erika, “Science of the Total Environment Corrigendum to ‘ Exploring the relationship between metal (loid) contamination rate , physicochemical conditions , and microbial community dynamics in industrially contaminated urban soils ’ [Sci . Total Environ . 897,” vol. 928, no. April, p. 172532, 2024.

[13] P. K. Tiwari, S. Samanta, F. Bona, E. Venturino, and A. K. Misra, “The time delays influence on the dynamical complexity of algal blooms in the presence of bacteria,” Ecol. Complex., vol. 39, no. November, 2019, doi: 10.1016/j.ecocom.2019.100769.

[14] X. C. JIN, S. R. WANG, J. Z. CHU, and F. C. WU, “Organic Phosphorus in Shallow Lake Sediments in Middle and Lower Reaches of the Yangtze River Area in China1 1 Project supported by the China’s National Basic Research Program: "Studies on the Process of Eutrophication of Lakes and the Mechanism of the Bl,” Pedosphere, vol. 18, no. 3, pp. 394–400, 2008, doi: 10.1016/S1002-0160(08)60030-2.

[15] S. Chen et al., “Temporal patterns of algae in different urban lakes and their correlations with environmental variables in Xi’an, China,” J. Environ. Sci., vol. 133, pp. 138–151, Nov. 2023, doi: 10.1016/J.JES.2022.07.036.

[16] N. Savenko and N. Prysiazhniuk, “Role of microorganisms of the aquatic environment in the formation of the ecological and sanitary state of water bodies,” Tehnol. virobnictva ì pererobki produktìv tvarinnictva, no. 2 (175), pp. 78–84, 2022, doi: 10.33245/2310-9289-2022-175-2-78-84.

[17] “Interactions of polychlorinated biphenyls and organochlorine pesticides with sedimentary organic matter of retrogressive thaw slump‐affected lakes in the tundra uplands adjacent to the Mackenzie Delta, NT, Canad.pdf.”

[18] L. Xianbiao, G. Dengzhou, L. Kaijun, and L. Xiaofei, “Bacterial community shifts driven by nitrogen pollution in river sediments of a highly urbanized city,” Int. J. Environ. Res. Public Health, vol. 16, no. 20, 2019, doi: 10.3390/ijerph16203794.

[19] L. A. Ibrahim and E. S. ElBastamy ElSayed, “The influence of water quality on fish tissues and blood profile in Arab al-Ulayqat Lakes, Egypt,” Egypt. J. Aquat. Res., vol. 49, no. 2, pp. 235–243, 2023, doi: 10.1016/j.ejar.2023.01.006.

[20] C. Lin and Y. Wang, “Distribution Patterns of Carbon , Nitrogen and Phosphorus (TOC-TN-TP) in Surface Sediment of Chaoshan Nearshore Waters and Environmental Ev

[21] V. P. A. Weerasinghe and K. Handapangoda, “Surface water quality analysis of an urban lake; East Beira, Colombo, Sri Lanka,” Environ. Nanotechnology, Monit. Manag., vol. 12, no. August, p. 100249, 2019, doi: 10.1016/j.enmm.2019.100249.

[22] Y. Zheng, J. Yu, Q. Wang, X. Yao, Q. Yue, and S. Xu, “What drives the changing characteristics of phytoplankton in urban lakes: Climate, hydrology, or human disturbance?,” J. Environ. Manage., vol. 351, p. 119966, Feb. 2024, doi: 10.1016/J.JENVMAN.2023.119966.

[23] W. Shen, Y. Jin, P. Cong, and G. Li, “Water environment response of urban water networks in the Pearl River Delta (China) under the influence of typhoon rain events,” Water Supply, vol. 23, no. 12, pp. 4840–4854, 2023, doi: 10.2166/ws.2023.321.

[24] S. Dong, Z. Li, Q. Chen, and Z. Wei, “Total organic carbon and its environmental significance for the surface sediments in groundwater recharged lakes from the Badain Jaran Desert, Northwest China,” J. Limnol., vol. 77, no. 1, pp. 121–129, 2018, doi: 10.4081/jlimnol.2017.1667.

[25] W. K. Dodds, “Trophic State and Eutrophication,” Freshw. Ecol., pp. 336–365, Jan. 2002, doi: 10.1016/B978-012219135-0/50018-0.

[26] X. Jin, Q. Xu, and C. Yan, “Restoration scheme for macrophytes in a hypertrophic water body, Wuli Lake, China,” Lakes Reserv. Sci. Policy Manag. Sustain. Use, vol. 11, no. 1, pp. 21–27, 2006, doi: 10.1111/j.1440-1770.2006.00291.x.

[27] D. Dharmarathna, R. Galagedara, S. Himanujahn, S. Karunaratne, and B. Athapattu, “Assessment of pollution state of Beira Lake in Sri Lanka using water quality index, trophic status, and principal component analysis,” Aquat. Ecol., pp. 1–24, 2023, doi: 10.1007/s10452-023-10052-8.

[28] J. Lan, M. Zhong, Y. Xu, Z. Wang, and H. Huang, “Applications of Cluster Analysis Method in Surface Water Quality Assessment: A Case Study in Balihe Lake, China,” Int. J. Environ. Prot. Policy, vol. 7, no. 3, p. 93, 2019, doi: 10.11648/j.ijepp.20190703.12.

Assessment of the Status of Microbiota Characteristics, Physico-Chemical Characteristics, Water Quality Index, and Trophic Level Index at Beira Lake, Colombo, Sri Lanka

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***Abstract*— Beira Lake, a significant water body in Colombo, Sri Lanka, faces severe ecological degradation due to rapid urbanization and anthropogenic activities. This research aims to evaluate the lake's health by integrating physico-chemical parameters, microbial diversity, and indices like the Water Quality Index (WQI) and Trophic Level Index (TLI). Water samples were collected from 20 strategically chosen locations, and key parameters such as temperature, pH, electrical conductivity, salinity, dissolved oxygen, biochemical oxygen demand at 20°C, chemical oxygen demand, ammonia, nitrate, and phosphate were measured. Microbial assessments included cyanobacteria, zooplankton, diatoms, aerobic bacteria, fecal coliforms, and chlorophyll-a content. The results showed significant spatial variability in water quality and microbial communities, with some locations exhibiting harmful cyanobacterial blooms, fecal contamination, and eutrophication. The WQI values indicated poor water quality, while TLI values confirmed hypertrophic conditions across the lake. A positive correlation between WQI and TLI underscores the interconnectedness of water quality and nutrient enrichment. This comprehensive assessment highlights the need for integrated management strategies to restore Beira Lake's ecological balance.**

Keywords*— *Beira Lake, water quality assessment, microbial diversity, Water Quality Index (WQI), Trophic Level Index (TLI), eutrophication

I. INTRODUCTION

Beira Lake, located in the heart of Colombo, Sri Lanka, is a significant man-made water body with a long history of serving the city's needs. Established by the Portuguese in 1551, the lake is not only a key landmark but also plays critical roles in flood control, groundwater recharge, and supporting urban wildlife habitats. Despite its importance, Beira Lake has experienced severe ecological degradation over recent decades, largely due to the rapid urbanization and associated anthropogenic activities within its catchment area. The resulting deterioration of water quality, frequent algal blooms, and sediment contamination have raised concerns about the lake's ability to perform its ecological functions.

Given the growing importance of sustainable water management, there is an urgent need for a comprehensive assessment of Beira Lake's health, with a particular focus on the relationships between microbial communities, water quality parameters, and nutrient levels. Microbiota, which include diverse microorganisms such as bacteria, algae, and fungi, play an essential role in maintaining lake health through processes like nutrient cycling, organic matter decomposition, and pollutant breakdown. These microorganisms not only act as indicators of pollution but are integral to the lake's ecological balance.

In addition to the microbiological assessment, analyzing the lake's physico-chemical characteristics is essential for evaluating its water quality. These parameters directly influence the lake's ability to support life and are fundamental to assessing its suitability for various uses, from recreation to ecological services. To provide a holistic assessment of Beira Lake's ecological health, this research aims to develop a comprehensive Water Quality Index (WQI) based on these physico-chemical parameters. The WQI serves as an invaluable tool for summarizing complex data into a single value that reflects overall water quality. Furthermore, this study calculated the Trophic Level Index (TLI), which measures the extent of nutrient enrichment and eutrophication within the lake. Eutrophication, primarily driven by excess nitrogen and phosphorus, is a key concern for urban lakes as it leads to algal blooms, oxygen depletion, and loss of biodiversity.

Overall, this study sought to comprehensively assess the health of Beira Lake by examining the intricate relationships between its microbial communities, physico-chemical properties, WQI, and TLI. Through a combination of microbial assessment, water quality evaluation, and spatial analysis, the findings offered insights into the lake's current ecological state and informed future management strategies for its restoration and long-term conservation.

II. MATERIALS AND METHODS

Description of the study sites

This study was in Beira Lake, Colombo, Sri Lanka. Beira Lake boasts a maximum depth of 5.6 meters and holds a water volume of approximately 2,903,000 cubic meters. The study focused on the four main basins of the lake: East Lake, Galle Face Lake, West Lake, and Southwest Lake In order to comprehensively assess the water quality of Beira Lake, twenty surface sampling locations were strategically chosen to cover the entirety of the lake, including its various basins,

proximity to inlets and outlets, and known pollution hotspots. The selection process was guided by water quality data collected by the Sri Lanka Land Development Corporation, which had previously conducted extensive monitoring at thirty-two locations within Beira Lake since 2019. These thirty-two locations were originally chosen to be representative of the lake's pollution status and to encompass all significant inflows and outflows.

For this research, the final twenty sampling locations were determined through an analysis of the historical water quality data provided by the Sri Lanka Land Development Corporation from their 2023 measurements. (Confidential data) Key parameters considered in this selection process included temperature, pH, Electrical Conductivity (EC), salinity, Total Dissolved Solids (TDS), Dissolved Oxygen (DO), ammonia, nitrate, phosphate, Biochemical Oxygen Demand (BOD_5) at 20°C, and Chemical Oxygen Demand (COD). This approach ensured that the chosen sampling sites were geographically diverse and representative of the varying environmental conditions and pollution levels across Beira Lake. The specific GPS coordinates and details of the surface sampling locations that studied in the research are provided in Table I and Figure 1.

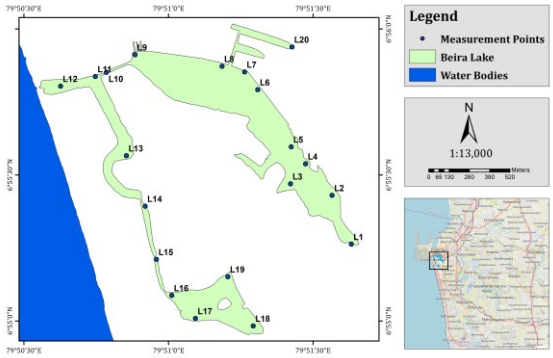

Fig. 12. Locations of surface sampling stations of study area

DETAILS ON LATITUDE, LONGITUDE OF SAMPLING LOCATIONS OF STUDY AREA

ID	Latitude	Longitude	ID	Latitude	Longitude
L1	6.93186	79.848068	L11	6.9261	79.847565
L2	6.931202	79.85308	L12	6.92322	79.848647
L3	6.929862	79.855135	L13	6.92018	79.849293
L4	6.926602	79.857063	L14	6.91919	79.853413
L5	6.921046667	79.860527	L15	6.91681	79.851547
L6	6.924497	79.857022	L16	6.916383	79.854872
L7	6.923996667	79.85852167	L17	6.918125	79.850182
L8	6.925633	79.85789167	L18	6.93033	79.85050667
L9	6.930616667	79.84578	L19	6.923837	79.859418
L10	6.930065	79.84377667	L20	6.9323055	79.85711117

1. Sample collection and laboratory analysis

Sample Collection: Water samples were collected in sterile containers between January and March 2024, following specific preservation guidelines to maintain microbiological integrity.

Physico-chemical Parameters: In-situ measurements, including temperature, pH, EC, salinity, TDS, and DO, were conducted with a calibrated multiparameter, while water clarity was assessed using a Secchi disc. Ex-situ parameters such as COD, BOD, ammonia, nitrate, phosphate, and total organic matter were analyzed using standard methods, including the APHA 5220 B method for COD and the Palintest 7100® photometer for nutrient analysis.

Microbial Parameters: Microbial diversity and density of cyanobacteria, diatoms, zooplankton, and aerobic bacteria were assessed through light microscopy and standardized protocols. Fecal coliform and *E. coli* content were evaluated using ISO 9308-2:1990, and chlorophyll-a content was measured using spectrophotometry.

Water quality index: The water quality of Beira Lake was evaluated using the Water Quality Index method, summarizing multiple water quality parameters into a single dimensionless value. The WQI model developed by Uddin et al. (2021) was applied to 20 sample stations across Beira Lake's basins (East, West, Southwest, and Galle Face). The selected parameters were BOD, COD, DO, nitrate, phosphate, ammonia, and pH. These parameters were chosen to provide a comprehensive understanding of the lake's water quality, covering both physicochemical and microbial aspects. The WQI was calculated by converting measured parameter concentrations into dimensionless sub-indices based on guidelines from the Central Environment Authority (CEA) of Sri Lanka. Sub-indices were derived directly from measured concentrations, with ammonia using Category C standards (for aquatic life). A weighted average approach was used to compute the final WQI.

All equations related to this calculation are given below, numbered from 1 to 4.

$$Q_n = \frac{V_n - V_i}{S_n - V_i} \quad (1)$$

$$K = \frac{1}{\left(\frac{1}{\sum_{i=1}^{n} S_n}\right)} \quad (2)$$

$$W_n = \frac{K}{S_n} \quad (3)$$

$$WQI = \frac{\sum W_n \times Q_n}{\sum W_n} \quad (4)$$

Where,

- Vn = the estimated value of the n^{th} parameter of the considered sampling station
- Vi = the ideal value of n^{th} parameter in pure water
- Sn = the standard permissible value for n^{th} parameter specified by CEA
- Qn = the quality rating for n^{th} parameter,
- K = the proportionality constant
- Wn = the Unit weight for n^{th} parameter
- WQI = Water Quality Index value for the sampling station

The calculated WQI values were categorized as shown below:

- WQI 0-25: Excellent (Class A)
- WQI 26-50: Good (Class B)
- WQI 51-75: Poor (Class C)
- WQI 76-100: Very Poor (Class D)
- WQI >100: Unfit for Consumption (Class E)

Trophic level index: TLI was calculated to assess the eutrophication status of Beira Lake. Parameters such as Chl-a concentration, Secchi disc depth, total phosphorus, and total nitrogen were used to compute the TLI, which provided a score representing nutrient levels and their impact on the lake's ecosystem.

The TLI was calculated using the following formulas, numbered 5 to 9.

$$TLI = \frac{\{TL(Chl-a) + TL(SD) + TL(TP) + TL(TN)\}}{4} \quad (5)$$

Where:

- TL(Chl−a) = Trophic Level for Chl-a concentration
$$TL(Chl-a) = 2.22 + 2.54 \log(Chl-a) \quad (6)$$
- TL(TP) = Trophic Level for Total phosphorus
$$TL(TP) = 0.218 + 2.92 \log(TP) \quad (7)$$
- TL(TN) = Trophic Level for Total nitrogen
$$TL(TN) = -3.61 + 3.01 \log(TN) \quad (8)$$
- TL(SD) = Trophic Level for Secchi disc depth
$$TL(SD) = 5.10 + 2.60 \log(1/SD - 1/40) \quad (9)$$

The TLI values were categorized as shown below:

- Ultra-microtrophic: Trophic Level < 1
- Microtrophic: Trophic Level 1 - 2
- Oligotrophic: Trophic Level 2 - 3
- Mesotrophic: Trophic Level 3 - 4
- Eutrophic: Trophic Level 4 - 5
- Supertrophic: Trophic Level 5 - 6
- Hypertrophic: Trophic Level > 6

This approach to WQI and TLI helps assess both water quality and nutrient levels, providing insight into Beira Lake's ecological health and its impact on microbial communities.

2. Data analysis

Spatial distribution analysis using ArcGIS Pro: ArcGIS Pro was used to visualize the spatial distribution of water quality parameters and microbial data across Beira Lake. Thematic maps were generated to display variations in physicochemical parameters such as pH, electrical conductivity, salinity, total dissolved solids, dissolved oxygen, water clarity, chemical oxygen demand, biological oxygen demand, ammonia, nitrate, phosphate, and total organic matter. These maps helped identify concentration patterns across the 20 sampling locations, revealing potential influences of different basins or nearby land use. Similarly, microbial parameters, including aerobic bacteria density, fecal coliform count, E. coli count, and Chlorophyll-a content, were mapped to examine microbial hotspots and their correlations with surrounding anthropogenic activities. Furthermore, the spatial distribution of the WQI and TLI was visualized, offering a comprehensive overview of water quality and eutrophication levels across Beira Lake. This analysis provided key insights into the spatial patterns of water quality, aiding in the identification of critical areas requiring attention.

Statistical analysis: Several statistical methods were used to analyze the collected data. A Pearson correlation coefficient was applied to identify relationships among all measured variables and between the two water quality indices, with a significance level of $\alpha = 0.05$. Fecal coliform and E. coli densities were categorized, and Analysis of Variance (ANOVA) was conducted to determine if there were significant differences between categories for each biological parameter. Tukey's HSD method was used to identify significant pairs of means. Multiple linear regression analysis was performed to model the relationships between microbiological parameters and physicochemical variables, using stepwise selection to identify significant predictors. Additionally, ordinal logistic regression was applied to explore how physical and chemical parameters impact the categorized densities of fecal coliform and E. coli. All statistical analyses were conducted using SPSS (Statistical Package for Social Science).

III. Result and Discussion

1. Physico-chemical Parameters

The water quality assessment of Beira Lake focused on key parameters such as pH, temperature, TDS, EC, and nutrient concentrations. pH values ranged between 9.803 and 10.237, indicating alkaline conditions, with certain locations (e.g., L16, L17, L18) showing deviations due to localized pollution. Temperature was more uniform, with values between 30.85°C and 31.57°C, though some areas exhibited slight thermal pollution. TDS levels varied from 143.16 to 171.04 mg/L, with higher values in L12, L14, and L20 pointing to pollution. EC and salinity were relatively stable, although higher levels at certain sites indicated increased dissolved salts. Nutrient concentrations, particularly ammonia, showed significant fluctuations, suggesting localized eutrophication. DO was stable, while COD and BOD showed higher variability, indicating areas of significant organic pollution. (Table II)

2. Biological Parameters

The diversity of cyanobacteria, zooplankton, and diatoms in Beira Lake was examined to assess the ecological health and biological diversity of the aquatic environment. Among the cyanobacteria, the dominant species identified included *Spirulina sp., Microcystis sp., Anabaena,* and *Planktothrix agardhii.* These cyanobacteria play a crucial role in shaping water quality, with some species, like *Microcystis sp.,* known to cause harmful algal blooms that can degrade water quality and produce toxins harmful to aquatic life and humans. The zooplankton community in the lake was diverse, comprising species such as *Brachionus calyciflorus, Trichocerca cylindrica, Keratella cochlearis, Ceriodaphnia comuta*, and various copepod species like *Microcyclops moghulensis.* Zooplankton are critical in aquatic ecosystems as they serve as primary consumers, linking phytoplankton and higher trophic levels like fish. Diatoms, including *Chaetoceros curvisetus, Chaetoceros lorenzianus, Leptocylindrus minimus, Proboscia alata,* and *Pseudo-nitzschia,* were also observed in the lake. These microorganisms are key primary producers, contributing to oxygen production and the overall productivity of the lake. However, the presence of *Pseudo-nitzschia species*, known to produce harmful toxins, raises concerns about the potential ecological risks in Beira Lake.

The assessment of various biological parameters in Beira Lake revealed significant findings regarding cyanobacterial density, chlorophyll-a content, fecal coliforms, E. coli, and aerobic plate counts. Cyanobacterial density varied widely, with Spirulina sp. dominating at a mean of 3811.17 cells/mL, while *Microcystis sp. and Anabaena* were present at lower densities, indicating potential for harmful algal blooms in

nutrient-rich areas. Chlorophyll-a concentrations ranged from 105.64 µg/L to 1330.81 µg/L, reflecting substantial variability in algal biomass, particularly in areas experiencing eutrophication. The presence of fecal coliforms was concerning, with nine locations exceeding 100 MPN/100mL, and E. coli levels surpassing 10 MPN/100mL in 11 locations, indicating significant microbial contamination likely due to sewage or runoff. Aerobic plate counts revealed a mean log value of 4.92 CFU/mL, showing relatively uniform bacterial presence across the lake, although some areas demonstrated higher counts, suggesting localized organic pollution. Collectively, these findings highlight the ecological challenges faced by Beira Lake, emphasizing the need for monitoring and remediation efforts to address pollution and maintain water quality.

3. *Estimated Indices*

The assessment of water quality in Beira Lake involved estimating two critical indices: the WQI and TLI. The WQI was calculated using parameters such as pH, nitrate, phosphate, ammonia, DO, COD and BOD. The mean WQI value was 464.98, with a high coefficient of variability (CV = 64.97%), indicating substantial variability in water quality across different locations in the lake. The spatial distribution of WQI revealed that sites such as L1, L3, L2, and L7 exhibited better water quality, while L13 and L14 were identified as highly polluted. Conversely, the TLI, which measures the trophic status of the lake based on chlorophyll-a concentration, nitrate, phosphate, and Secchi depth, had a mean value of 6.90 and a lower CV (7.11%), suggesting more uniform conditions. The TLI map indicated oligotrophic conditions in locations like L2 and L7, while eutrophic conditions were observed in L20, L10, and L14, reflecting significant nutrient pollution. A notable positive correlation between WQI and TLI (R = 0.715) emphasized that higher nutrient levels were associated with poorer water quality. Together, these indices highlighted the ecological challenges faced by Beira Lake and the urgent need for pollution mitigation efforts to restore water quality and balance within the ecosystem.

STATISTICAL SUMMARY OF BEIRA LAKE TESTED PARAMETERS

Parameters	Min	Max	Mean	Standard Deviation
pH	9.30	10.90	10.02	0.104
Temperature (°C)	29.70	32.40	31.21	0.770
TDS (mg/l)	108.00	241.00	157.10	29.790
EC (µs/cm)	282.00	491.00	321.30	55.490
Salinity (%)	0.13	0.25	0.15	0.030
Phosphate (mg/L)	0.46	3.40	1.54	0.970
Nitrate (mg/L)	0.07	0.18	0.12	0.030
Ammonia (mg/L)	0.60	10.80	3.36	3.140
DO (mg/L)	10.57	21.67	17.01	3.390
COD (mg/L)	27.00	345.00	79.90	67.700
BOD (mg/L)	40.00	252.00	93.80	67.030
Secchi Depth (m)	0.01	0.24	0.16	0.080
Organic Carbon in sediment % (w/w)	0.29	22.23	10.68	5.850
Spirulina Sp. (cells/ mL)	0.00	9373.33	3811.17	3578.830
Microcystis Sp. (cells/ mL)	208.33	6918.33	1283.42	1907.080
Anabaena (cells/ mL)	0.00	43.33	10.83	13.330
Planktothrix agardhii (cells/ mL)	0.00	61.67	34.17	18.110
Chlorophyll -a (µg/L)	105.64	1330.81	343.09	313.380
Aerobic Plate Count (log (CFU/mL))	3.15	7.38	4.92	4.820
WQI	183.69	1538.67	464.98	302.110
TLI	6.23	7.86	6.90	0.490

4. *Relationships among Physico-chemical Parameters*

The analysis of relationships among physico-chemical parameters in Beira Lake, based on Pearson correlation coefficients, revealed several significant interactions. pH showed significant negative correlations with nitrate (R = -0.62) and ammonia concentrations (R = -0.47), while positively correlating with biochemical oxygen demand (BOD) (R = 0.47) and temperature (R = 0.55). Nitrate concentration was negatively correlated with BOD (R = -0.49) but positively correlated with total dissolved solids (TDS) (R = 0.49). Ammonia concentration had significant positive relationships with chemical oxygen demand (COD) (R = 0.63), TDS (R = 0.52), electrical conductivity (EC) (R = 0.56), and salinity (R = 0.73). BOD was positively correlated with temperature (R = 0.55) and negatively with Secchi depth (R = -0.77). Notably, the strongest correlations were between EC and salinity (R = 0.94), and both EC and salinity showed high positive relationships with TDS. These correlations indicated that nitrate and ammonia negatively impacted pH while maintaining alkaline conditions. Additionally, changes in BOD and temperature had a weak effect on pH, and fluctuations in ammonia and COD levels influenced other parameters.

5. *Relationships among Biological parameters*

In the ANOVA teste results, Spirulina species had significant (P<0.05) relationship with E. coli density categories. According to the Tukey test, there is a significant different between mean density of Spirulina species in second category (2095.185cell count/ mL) and third category (7434.1665 cell count/ mL). (Figure 2)

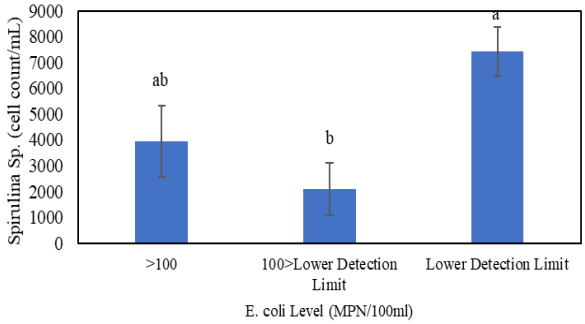

Fig. 13. *Spirulina Sp.* versus *E. coli* Level

6. *Correlations of indices*

There was significant (P<0.05) positive correlation (R = 0.715) was found between WQI and TLI. Furthermore, few relationships were found between indices and a measured variable that was not used to calculate those indices. When considering the WQI, TDS (R = 0.555), EC (R = 0.717) and salinity (R = 0.791) have shown positive (P<0.05) relationships while Secchi depth (R = -0.443) and cell count per mL of Spirulina species (R = -0.454) have negative (P<0.05) correlations with WQI. TLI has significant positive relationships with TDS (R = 0.539), EC (R = 0.58), salinity (R = 0.575), and Aerobic plate count (R = 0.52). Results have demonstrated that the factors that were positively related to TDS, EC and salinity have been influenced to both quality

indices. The relationships of Ammonia and COD with both EC and salinity would explain the situation for WQI. But for TLI, different factors had been affected on TLI.

7. Relationships of biological parameters with physicochemical parameters and indices

Chlorophyll –a: According to correlation analysis, chlorophyll-a with Secchi depth (R = -0.675). There is no any other correlation was found. In multiple linear regression analysis, stepwise selection procedure has selected the Secchi depth as the only significant independent variable. Model Adjusted R^2 was 0.425. ANOVA table of the regression was shown that regression between concentration of chlorophyll-a and Secchi depth was significant (P < 0.05). According to analysis model equation is (Equation 10);

Concentration of chl-a (mgL^{-1})

$$= 778.684 - 2752.546 \times \text{Secchi depth (m)} \quad (10)$$

According to above equation 10, chlorophyll-a content when Secchi depth is 0m is 778.684mg/L. if Secchi depth is increased by 1m, chlorophyll content would be reduced by 2752.546 mg/L (Figure 3)

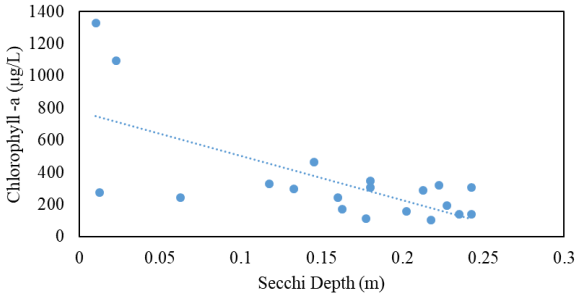

Fig. 14. *The relationship between chl -a and secchi depth*

Aerobic Plate Count (APC): Log value of Aerobic plate count have significant (P<0.05) positive correlations with the pH (R = 0.488) and BOD (R = 0.450). However, only pH value has selected as the independent variable for the final model. Aerobic Plate Counts of L4 and L18 were identify as the outlier by analysis procedure. The adjusted R^2 which is the adjusted proportion between the variability represented by the selected model and the total observed variability of the Selected multiple linear regression model was 0.365. The regression model of Aerobic Plate Count against COD and pH is significant at 0.05 alpha level as exhibited in the ANOVA results. The final regression model is as follows (Equation 11);

$$\text{APC (log (CFU/mL))} = 1.006 \times \text{pH} \quad (11)$$

Above regression equation 11 has expressed that when COD remained constant and pH increased by a unit, aerobic plate count would increase by 1.006 log (CFU/mL) (Figure 4).

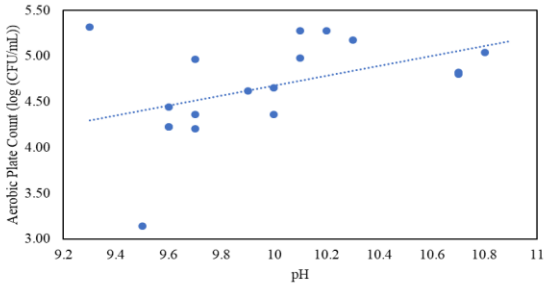

Fig. 15. *The relationship between aerobic plate count and pH*

Fecal coliform: According to goodness of fit results, categories of the fecal coliform density had significant ($\varkappa 2$ = 128.7) (P<0.05) associations with some independent variables and there is no significant different with full model and predicted model ($\varkappa 2$ = 28.9) (P>0.05) (no significant different with observed and predicted probabilities). Following model (Equation 12) was determined by the results of parameter estimation.

$$\ln\left[\frac{P\,(Y > i)}{P\,(Y \leq i)}\right] = 6.342 \times pH - 0.036 \times COD\,(mgL^{-1}) - 0.33 \times OGSD\,\left(\%\frac{w}{w}\right) + 0.135\,TDS(mgL^{-1}) \quad (12)$$

Where; i = 1,2,3 (categories)

- (OGSD = organic content in sediments)
- ln [(P(Y> i) / (P(Y≤ i)] = log odd value

ln [(P(Y > i) / (P(Y ≤ i)], Odd value is the ratio between probability of be a higher category than i^{th} category {P(Y > i)} and probability of be the i^{th} category or lower category {P(Y < i)}

There was no significant intercept in the results. Therefore, the model concluded for all tested categories. When all other parameters were held constant, a one-unit increase in pH led to an increase in the log-odds value by 6.342, indicating a positive association between pH and fecal coliform density. Conversely, when COD increased by one unit, while all other independent parameters remained constant, the log-odds value decreased by 0.036, suggesting a negative interaction between COD and fecal coliform density. The results also indicated a negative association between OGSD and fecal coliform density. In contrast, TDS showed a significant positive association with fecal coliform density.

E. coli: According to the goodness-of-fit test results, no significant association (P > 0.05) was found between the categorical variable of E. coli density and the independent variables (χ^2 = 24.9). Additionally, there was no significant deviation (P > 0.05) between the full model and the predicted model (χ^2 = 14.29).

Cyanobacteria Diversity - *Spirulina sp.:* Negative significant relationships were found between the density of Spirulina species and ammonia content (R = -0.48), electrical conductivity (R = -0.473), and salinity (R = -0.521). Multiple linear regression results revealed that the density of Spirulina species (cells/mL) had a significant regression only with salinity, due to the multicollinearity effect generated by correlations among parameters related to Spirulina species density. The highest correlation with Spirulina species count was found with salinity, and all other variables showed

significantly higher relationships with salinity. Therefore, the variance among correlated variables and the dependent variable could be modeled using only salinity, thereby removing the multicollinearity effect. ANOVA results confirmed the significance of the regression model ($P < 0.05$), with the model's adjusted R^2 being 0.231. Model equation is as follows (Equation 13);

Density of *Spirulina Species* (Cell count per mL)

$$= 12706.42 - 57949.545 \times \text{Salinity (\%)} \quad (13)$$

Without salinity, density was 12706.42 cell count/mL (Intercept). According to model, density would be declined by 57949.545 cell count/mL when the salinity increased by 1%. (Figure 5)

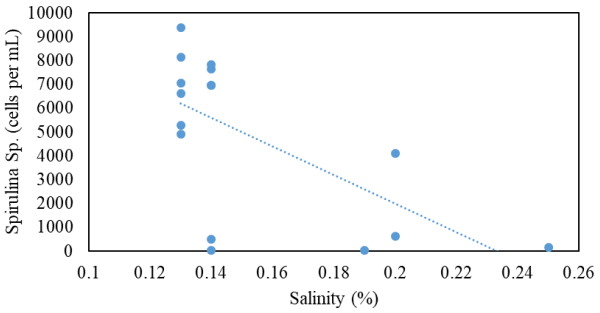

Fig. 16. *The relationship between Spirulina Sp. and salinity*

Microcystis Sp.: Cell count per mL of *Microcystis Sp.* had shown only one positive ($P<0.05$) correlation and it was with pH ($R = 0.447$). Multiple linear regression analysis selected only pH as the significant independent variable for density of *Microcystis Sp.* model adjusted R^2 value was 0.244 and based on ANOVA test, regression of those variables is significant ($P<0.05$). The regression model of the density of *Microcystis Sp* was as follows (Equation 14);

Density of *Microcystis Sp* (cell count mL-1)

$$= 2675.46 \times \text{pH} - 25466.825 \quad (14)$$

Above regression model equation 14 has expressed that when pH increased by a unit, density of *Microcystis Species* would be rise by 2675.46. (Figure 6)

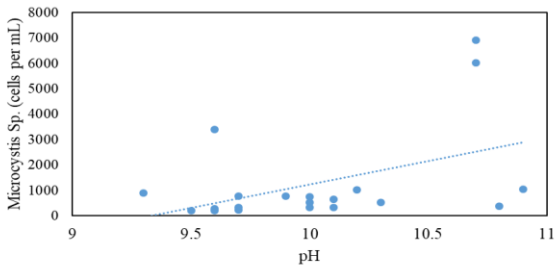

Fig. 17. The relationship between *Microcystis Sp. and pH*

Anabaena: The *Anabaena* cell count per mL was ($P < 0.05$) positively correlated with the Nitrate content ($R = 0.488$). According to model summary, adjusted R^2 of the regression between *Anabaena* cell count and nitrate content was 0.234 and the ANOVA test result reviled that this regression model was significant at 0.05 alpha level. Regression equation between *Anabaena* cell count and nitrate content is as follows (Equation 15);

Anabaena (cell count mL^{-1})

$$= 235.264 \times \text{Nitrate (mgL}^{-1}\text{)} \quad (15)$$

Regression model 5.6 is explained that *Anabaena* cell count per mL will increase by 235.264, when nitrate content increased by 1mg/L. (Figure 7)

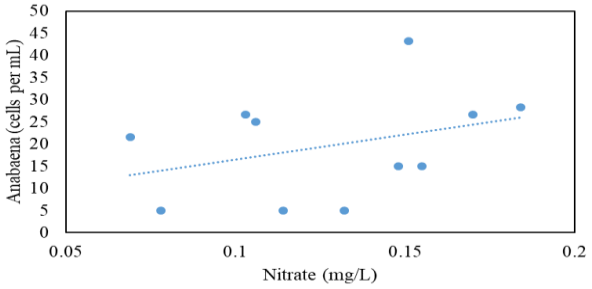

Fig. 18. The relationship between *Anabaena* and nitrate

Planktothrix agardhii: The cell counts per mL of *Planktothrix agardhii* has shown negative ($P<0.05$) correlation with Phosphate content ($R = -0.608$). The Phosphate content and Ammonia content was the selected independent variable for the final model by the stepwise selection procedure. The Model correlation between dependent variable and independent variables of the Final model was 0.723 and the adjusted R^2 value was 0.466. therefore, the final model could be predicted 46.6% from the observed variance. The regression model was found to be significant ($P<0.05$) by ANOVA test (Figure 8,9). Final model of the cell counts per mL of *Planktothrix agardhii* is as follows (Equation 16);

Planktothrix agardhii (cell count mL^{-1})

$$= 48.639 - (14.856 \times \text{Phosphate content (mgL}^{-1}\text{)}) + (2.488 \times \text{Ammonia content (mgL}^{-1}\text{)}) \quad (16)$$

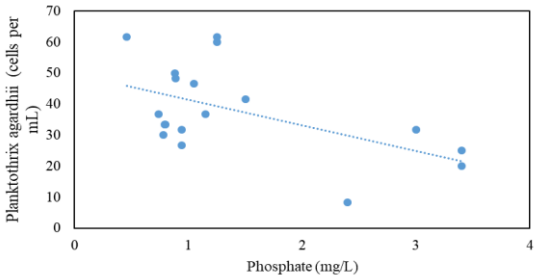

Fig. 19. The relationship between *Planktothrix agardhii* and phosphate

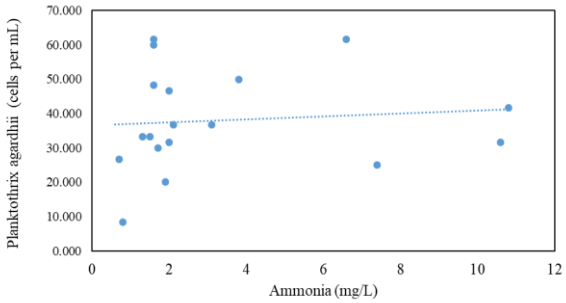

Fig. 20. The relationship between *Planktothrix agardhii* and ammonia

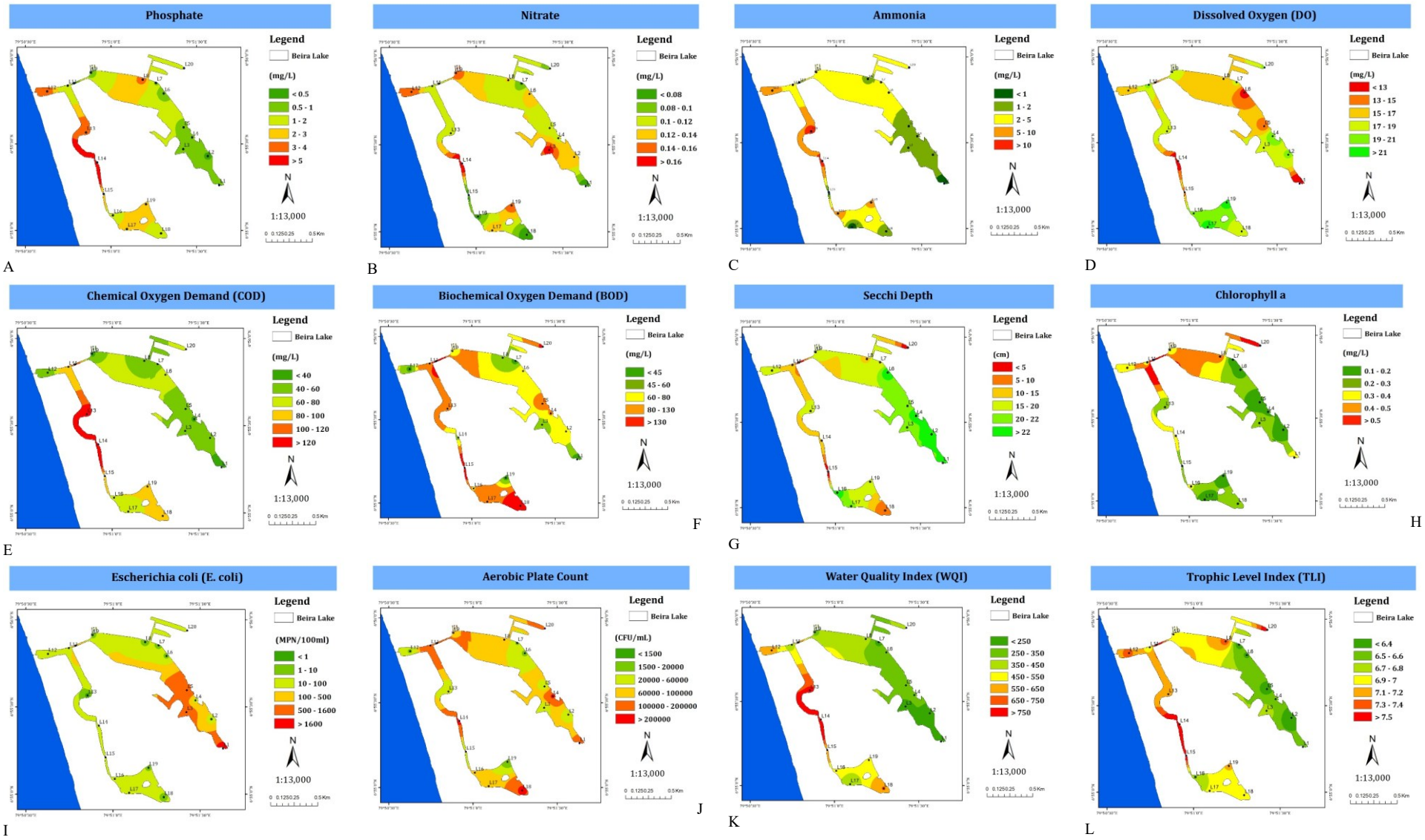

Fig. 21. Mapping Spatial Distribution of Water Quality Parameters Using GIS in Groundwater of the Beira Lake, Sri Lanka (A – phospate distribution, B – nitrate distribution, C – amonia distribution, D – DO distribution, E - COD distribution, F - BOD distribution, G – secchi depth distribution, H – chlorophyl a distribution, I – E.coli distribution, J – aerobic plate count distribution, K – WQI distribution, L – TLI distribution)

IV. Conclusion

The comprehensive study on Beira Lake's ecological health has provided key insights into the intricate relationships between its microbiota, physico-chemical parameters, and nutrient indices such as the Water Quality Index (WQI) and Trophic Level Index (TLI). The findings indicate significant spatial variability in water quality and nutrient enrichment across the lake. Key insights include the identification of harmful cyanobacterial blooms, fecal contamination, and localized eutrophication. The WQI values, which point to poor water quality, were closely aligned with the TLI, confirming hypertrophic conditions driven by high nutrient loads. Spatial analysis using ArcGIS (figure 10) revealed critical pollution hotspots, such as locations L13 and L14, with higher concentrations of pollutants and microbial contamination. These areas are particularly vulnerable and require targeted remediation efforts. The strong positive correlation between WQI and TLI emphasizes the interconnectedness of water quality and nutrient enrichment. Moreover, the relationships between physico-chemical parameters (e.g., pH, nitrate, ammonia) and microbial species (e.g., *Spirulina sp., Microcystis sp.*) highlight the significant role of nutrient levels in shaping microbial communities. For instance, the regression models suggest that higher salinity negatively impacts Spirulina populations, while increased nitrate content supports the growth of *Anabaena species*.

This research underscores the importance of integrated management strategies to mitigate pollution and restore ecological balance in Beira Lake. Future studies should focus on long-term monitoring and the implementation of sustainable solutions to improve water quality and safeguard biodiversity. The insights gained from this research contribute to a deeper understanding of urban lake ecosystems and their responses to anthropogenic pressures..

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References

[1] Writer's Handbook. Mill Valley, CA: University Science, 1989.

[2] D. R. Pearsall et al., "Environmental Reviews and Case Studies: 'Make No Little Plans': Developing Biodiversity Conservation Strategies for the Great Lakes," Environ. Pract., vol. 15, no. 4, pp. 462–480, 2013, doi: 10.1017/s1466046613000410.

[3] W. H. Sugiharto, M. I. Ghozali, S. Suryono, H. Susanto, and M. A. Budihardjo, "Online monitoring of water pollution level based on dissolved oxygen (DO) and biochemical oxygen demand (BOD) using wireless sensor system," J. Phys. Conf. Ser., vol. 1943, no. 1, 2021, doi: 10.1088/1742-6596/1943/1/012016.

[4] X. David and E. Daniel, "Article (refereed) - postprint," 2020.

[5] M. Fiello, A. T. Mikell, M. T. Moore, and C. M. Cooper, "Variability in the characterization of total coliforms, fecal coliforms and Escherichia coli in recreational water supplies of North Mississippi, USA," Bull. Environ. Contam. Toxicol., vol. 93, no. 2, pp. 133–137, 2014, doi: 10.1007/s00128-014-1299-1.

[6] X. Zhang et al., "Characteristic analysis of phospholipid fatty acids (PLFAs) in typical nutrient polluted lake sediment in Wuhan," Int. J. Sediment Res., vol. 36, no. 2, pp. 221–228, 2021, doi: 10.1016/j.ijsrc.2020.09.002.

[7] Y. Wang, Y. Guo, Y. Zhao, L. Wang, Y. Chen, and L. Yang, "Spatiotemporal heterogeneities and driving factors of water quality and trophic state of a typical urban shallow lake (Taihu, China)," Environ. Sci. Pollut. Res., vol. 29, no. 35, pp. 53831–53843, 2022, doi: 10.1007/s11356-022-18519-1.

[8] L. Zhang, Y. J. Xu, and S. Li, "Changes in CO2 concentration and degassing of eutrophic urban lakes associated with algal growth and decline," Environ. Res., vol. 237, p. 117031, Nov. 2023, doi: 10.1016/J.ENVRES.2023.117031.

[9] E. Jaiani et al., "Microbial water quality of recreational lakes near Tbilisi, Georgia," J. Water Health, vol. 11, no. 2, pp. 333–345, 2013, doi: 10.2166/wh.2013.057.

[10] A. E. Barbosa, "Analysis of Methodologies for Assessment of Urban Drainage Impacts in Lakes and Reservoirs," Open Environ. Biol. Monit. J., vol. 5, no. 1, pp. 30–38, 2013, doi: 10.2174/1875040001205010030.

[11] A. H. M. J. Alobaidy, H. S. Abid, and B. K. Maulood, "Application of Water Quality Index for Assessment of Dokan Lake Ecosystem, Kurdistan Region, Iraq," J. Water Resour. Prot., vol. 02, no. 09, pp. 792–798, 2010, doi: 10.4236/jwarp.2010.29093.

[12] S. G. Ghebremedhin and B. Sen Gupta, "Spatio-Temporal Water Quality Assessment and Pollution Source Apportionment of Lake Chamo using Water Quality Index and Multivariate Statistical Techniques," vol. 4, no. 1, pp. 11–19, 2023.

[13] T. Miller et al., "Predictive Modeling of Urban Lake Water Quality Using Machine Learning: A 20-Year Study," Appl. Sci., vol. 13, no. 20, p. 11217, 2023, doi: 10.3390/app132011217.

[14] Q. Assessment and D. Indices, "of Agricultural Sciences Water Quality Assessment and Eutrophic Classification of Hanoi Lakes Using," vol. 4, no. 4, pp. 1229–1240, 2021.

[15] A. de la Cruz, R. Logsdon, D. Lye, S. Guglielmi, A. Rice, and M. S. Kannan, "Harmful Algae Bloom Occurrence in Urban Ponds: Relationship of Toxin Levels with Cell Density and Species Composition.," J. earth Environ. Sci., vol. 25, pp. 704–726, 2017, doi: 10.29011/JEES-148.100048.

[16] S. Björk, "Goals, methods and possibilities for directing development of limnic ecosystems," *Hydrobiologia*, vol. 86, no. 1–2, pp. 177–183, 1982, doi: 10.1007/BF00005808.

[17] A. K., "Water Quality Analysis of Bhishma Lake At Gadag City," *Int. J. Res. Eng. Technol.*, vol. 05, no. 03, pp. 320–327, 2016, doi: 10.15623/ijret.2016.0503060.

[18] X. C. JIN, S. R. WANG, J. Z. CHU, and F. C. WU, "Organic Phosphorus in Shallow Lake Sediments in Middle and Lower Reaches of the Yangtze River Area in China1 1 Project supported by the China's National Basic Research Program: "Studies on the Process of Eutrophication of Lakes and the Mechanism of the Bl," *Pedosphere*, vol. 18, no. 3, pp. 394–400, 2008, doi: 10.1016/S1002-0160(08)60030-2.

[19] L. Paruch, A. M. Paruch, H. G. Eiken, and R. Sørheim, "Faecal pollution affects abundance and diversity of aquatic microbial community in anthropo-zoogenically influenced lotic ecosystems," *Sci. Rep.*, vol. 9, no. 1, pp. 1–13, 2019, doi: 10.1038/s41598-019-56058-x.

[20] X. Yao, J. Lu, Z. Liu, D. Ran, and Y. Huang, "Distribution of sterols and the sources of pollution in surface sediments of Ulungur lake, Xinjiang," *Water Sci. Technol.*, vol. 67, no. 10, pp. 2342–2349, 2013, doi: 10.2166/wst.2013.107.

[21] S. Chen *et al.*, "Temporal patterns of algae in different urban lakes and their correlations with environmental variables in Xi'an, China," *J. Environ. Sci.*, vol. 133, pp. 138–151, Nov. 2023, doi: 10.1016/J.JES.2022.07.036.

[22] U. S. Bagde and A. K. Rangari, "Periodicity of coliform bacteria in an aquatic environment," *Water Sci. Technol.*, vol. 40, no. 7, pp. 151–157, 1999, doi: 10.1016/S0273-1223(99)00594-6.

Develop an Allometric Model to Estimate the Total Carbon Sequestration Potential of Coconut Cultivation

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***Abstract*: The coconut palm (*Cocos nucifera* L.) is an important tropical tree crop grown extensively across the tropical belt of the world. In addition to their numerous food and non-food uses, coconut palm plays a vital role in mitigating climate change through carbon sequestration. Accurately quantifying the carbon sequestered by coconut palms is crucial for assessing their climate change mitigation potential and inclusion in carbon trading schemes. This study focused on estimating the carbon sequestration potential of coconut cultivations in Sri Lanka using a multidisciplinary approach combining field measurements, laboratory analyses, and modeling techniques. Coconut palms were selected from age categories to estimate the total carbon stock. The selected age categories were 10, 20, 30, 40, and 50 years and the estimated carbon stocks for each age category were 22.59 Mg[C]ha^{-1}, 34.99 Mg[C]ha^{-1}, 53.13 Mg[C]ha^{-1}, 63.40 Mg[C]ha^{-1}, and 66.03 Mg[C]ha^{-1}, respectively. An allometric equation was developed to estimate the total carbon stock in coconut palm (TC) using four equations which had been developed by previous studies and above results; TC = (0.0073 × a) + 0.0852, where "TC' is the total carbon stock and "a" is the age (year) of the palm.**

***Keywords*: Allometric equation, Carbon sequestration, Carbon stock, Climate change**

I. Introduction

Climate change is one of the most pressing global challenges of our time, and carbon sequestration has emerged as a crucial strategy to mitigate its impacts [1],[2],[3]. Carbon sequestration is the process of keeping CO_2 in the atmosphere for a long time by using terrestrial ecosystems, such as forests, soil, or agricultural systems [4]. This process is considered to play a significant role in regulating the Earth's carbon cycle and it has received lots of attention due to its potential to reduce the rising levels of greenhouse gases (GHGs) in the atmosphere. Sri Lanka, an island nation in the Indian Ocean, is particularly vulnerable to the impacts of climate change, including rising sea levels, changes in precipitation patterns, and increased frequency and intensity of extreme weather events. As a signatory to the Paris Agreement Sri Lanka has pledged to cut down on GHG emissions and increase its carbon sinks [5]. In this context, exploring sustainable agricultural practices that can contribute to carbon sequestration has become a priority.

Different approaches have been created to measure carbon capture in multi-purpose tree planting, for example, allometric equations, remote sensing techniques, and process-based models [6]. Allometric equations relate easily measurable tree parameters, such as diameter at breast height (DBH) and height and age, to biomass and carbon content [7]. The application of such an allometric equation proves a veritable convenient and alternative technique to the destructive sampling of carbon stock. Deriving from the empirical link among dimensions of trees and their carbon content, this method enables producing data with high accuracy, as well as the ones that can be reproduced, whilst contributing to our understanding of carbon capture processes occurring within the interpreted ecosystem [8]. This study focused on estimating the carbon sequestration potential of coconut palms in Sri Lanka using a multidisciplinary approach combining field measurements, laboratory analyses, and modeling techniques. It involved developing an allometric model for non-destructive estimation of carbon stock. It includes assessing the carbon stocks in various components of the system, including the coconut stands in different age groups. By estimating the total carbon sequestration potential, this study contributed to the development of strategies for enhancing carbon sinks in agricultural landscapes. It also supported the implementation of climate-smart agriculture practices and the promotion of agroforestry systems as a means of mitigating greenhouse gas

emissions while ensuring food security and sustainable livelihoods for farming communities in Sri Lanka.

II. Methodology

1. location of the Experiment

The experiment was conducted at the Coconut Research Institute of Sri Lanka, Lunuwila (7°19'39" N, 79°52'5" E), which is situated in the Low Country Intermediate Zone (IL1a) [9]. The data collection was done from January to December 2023. The dominant soil types of the IL1a Agro-Ecological Zone are the Red Yellow Podzolic soils with mottled subsoils, together with Regosols on old red and yellow sands [10].

2. Data Collection

Total carbon stock of coconut stands

Coconut stands belonging to age groups of 10, 20, 30,40, and 50 years were selected, and 9 palms were randomly selected from each age category to estimate the above-ground and below-ground carbon content of the coconut palms.

The methods followed by Ranasinghe and Thimothias, 2015 [11], were used to determine the carbon stock of above-ground biomass.

Nut counts of each developing bunch were recorded every month. Two nuts were selected from each bunch and the length of nuts along the long axis was measured. The dry weight of each nut was estimated to be non-destructively using the following equation developed for the tall variety of coconut [12].

$DM \log = 0.1486 + (0.1472\ (L\text{-vertical})) - (0.000741(L\text{-vertical})^2)$ ……..01

Were, DM - Total dry matter content of the nut (g)

L - Vertical length of the nut along the vertical axis (cm)

The dry weight of each bunch was estimated by calculating the average weight of the nuts and multiplying it by the number of nuts per bunch. The total dry weight of the nuts on a palm was then determined by summing the weights of all the bunches.

The stem density of coconut was estimated based on the age of the plantation. The stem dry weight of a palm was calculated by multiplying the stem's volume by its density Friend & Corley, 1994 [13], assuming the stem was cylindrical without considering its tapering towards the top.

$D = 0.0079t + 0.18$……..02

Where, D – Density (g cm^{-3})

t - Age after field planting (Years)

The dry weight of a frond per palm was estimated by using a cross-section area of the petiole at the point of attachment of the lowest leaflet and measuring the width and depth of the petiole on the coconut leaves [13]. Finally, the total dry weight of the crown was calculated by multiplying the dry weight of a frond with the number of fronds in the entire canopy.

$W = 0.13C - 0.25$……..03

Where, W - Dry weight of the frond (g)

C - Width × depth of the petiole

The carbon content of the dry mass was assumed to be 0.5 g of carbon for 1 g of dry biomass [14],[15].

Using the height of the coconut palms, the allometric relationship was created to accurately estimate the amount of carbon stocks in the roots of the entire palm [16].

$R = 0.0074h + 0.0035$……..04

Were, R - Root Carbon Stock (Mg[C] palm)

h - Height of the Palm (m)

The total carbon stock per hectare was calculated by extrapolating the carbon stock per palm based on the number of palms present in each hectare of land.

3. Statistical Analysis

R (4.1.3) statistical software was used to perform all the statistical analyses. First, a regression analysis was employed to develop an allometric model to estimate the total carbon stock of a given coconut plantation using the age of the coconut palms in the plantation. Then, the One-way Analysis of Variance (ANOVA) was applied at a 5% level of significance. This statistical test was aimed at identifying whether there are any statistically significant variations among the mean carbon stock across different criteria. Subsequently, Tukey's honestly significant difference (HSD) test was employed to conduct pairwise comparisons and identify specific differences between the means.

III. Results and Discussion

Determination of Carbon Stock in Coconut Palms

The carbon stock variation among coconut palms of five different age categories was investigated in this study. Carbon stocks in coconut fronds declined significantly with age ($P < 0.05$). The highest carbon stock of 8.92 Mg[C]ha^{-1} was observed in the 10-year age group, while the lowest value of 3.38 Mg[C]ha^{-1} was recorded in the 50-year age group (Figure 1). This decline can be attributed to several factors identified in previous studies, such as the elongation of leaves up to 10 years followed by progressive reduction, a decrease in the length and width of the longest leaflets with age, and a decline in the total number of leaflets in mature green leaves after 20 years [17].

Significant differences ($P < 0.05$) in the total carbon stock of the stem were notably observed across the five age categories. The highest carbon stock of 42.90 Mg[C]ha^{-1} was observed in the 50-year age group, while the lowest value of 7.02 Mg[C]ha^{-1} was recorded in the 10-year age group. However, there was no significant difference between the 40 and 50-year-old palms nor between the 10 and 20-year-old ones (Figure 2). Carbon stock in coconut stems exhibited a consistent increase with age, with a notable accumulation observed between 20 and 40 years. This finding aligns with previous research conducted by Raveendra et al. 2017 [18], which reported similar carbon stock values (28.72 Mg[C]ha^{-1}) for 30-year-old coconut palms.

In nuts, significant differences ($P < 0.05$) in carbon stocks were observed among age categories, although there was no significant ($P < 0.05$) difference between the 30, 40, and 50-year-old palms. The 10-year-old palms only showed significance in age groups 30, 40, and 50. The highest carbon stock of 1.89 Mg[C]ha^{-1} was observed in the 50-year age group, while the lowest value of 0.72 Mg[C] ha^{-1} was

recorded in the 10-year age group (Figure 3). This finding is consistent with the results of Raveendra et al. (2017), which reported similar carbon stock values (1.99 Mg[C]ha^{-1}) for 30-year-old coconut palms.

Root carbon stocks also varied among the five age categories, with 30, 40, and 50-year-old palms exhibiting no significant difference ($P < 0.05$). The highest carbon stock of 17.85 Mg[C]ha^{-1} was observed in the 50-year age group, while the lowest value of 5.93 Mg[C]ha^{-1} was recorded in the 10-year age group (Figure 4). An increasing trend in root carbon stock was identified among the five age groups.

Interestingly, significant differences ($P < 0.05$) in total carbon stocks among the five age categories were primarily observed in 50-year-old palms, with the carbon stock significantly differing from age groups 10 and 20. The highest total carbon stock of 66.03 Mg[C]ha^{-1} was observed in the 50-year age group, while the lowest value of 22.59 Mg[C]ha^{-1} was recorded in the 10-year age group (Figure 5). An increasing trend in total carbon stock was identified up to 40 years and then among the five age groups.

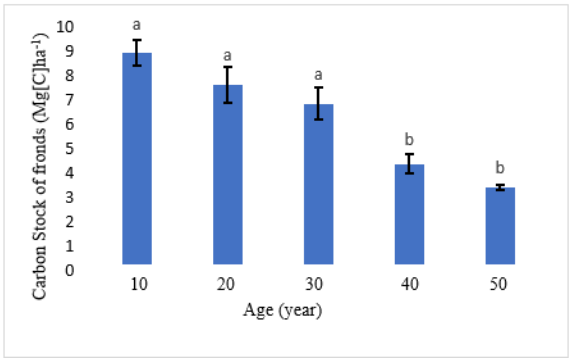

Figure 1: Variation of Coconut carbon stock with different age groups; Carbon stock of fronds

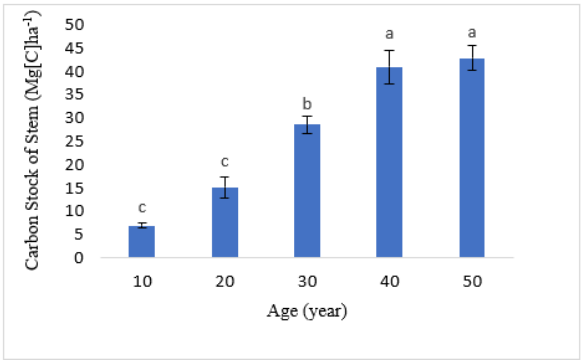

Figure 2: Variation of Coconut carbon stock with different age groups; Carbon stock of stems

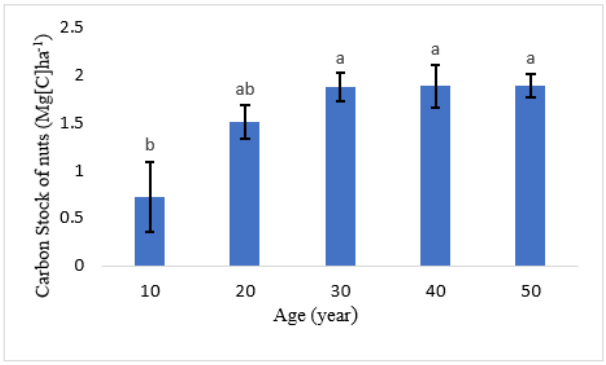

Figure 3: Variation of Coconut carbon stock with different age groups; Carbon stock of nuts.

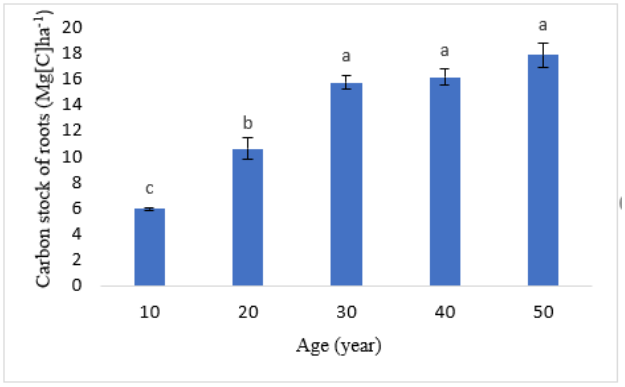

Figure 4: Variation of Coconut carbon stock with different age groups; Carbon stock of roots.

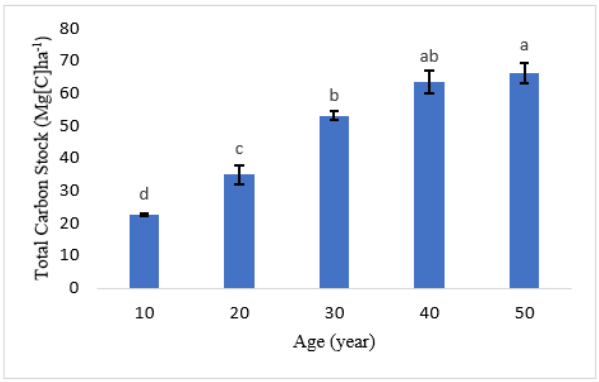

Figure 5: Variation of Coconut carbon stock with different age groups; Total carbon stock.

(Means that do not share a letter are significantly different in $P<0.05$)
The assumption: There are 158 coconut palms in one hectare

IV. Developed Allometric Models and Validation

An allometric equation was developed to accurately estimate the total carbon stock in coconut palms. This equation, expressed as $TC = (0.0073 \times a) + 0.0852$, where "TC" represents total carbon stock in coconut palm and "a" denotes by age of the palm in years demonstrated a robust fit with an

impressive R^2 value of 0.94. This high R^2 value affirms the model's efficacy and accuracy, indicating that palm age is a significant determinant in estimating carbon storage within coconut cultivation. The derived equation thus serves as a valuable resource for both scientific research and practical application, providing a reliable means to evaluate and enhance the carbon sequestration capabilities of coconut palm. In allometric models, the R^2 statistic represents the proportion of variance in the dependent variable explained by the independent variable. Higher R^2 values indicate a better fit, meaning the model is more accurate [19].

V. Conclusion

This comprehensive approach yielded valuable insights into the significant role of coconut cultivation in mitigating climate change through carbon sequestration. One of the key achievements of this research was the development of an allometric equation for non-destructive estimation of the total carbon stock in coconut palms. The equation, which exhibited a strong fit with the data, provides a practical tool for researchers and practitioners to reliably assess the carbon sequestration potential of coconut cultivations. The study revealed that carbon stocks in various components of coconut cultivation. Notably, the total carbon stock increased substantially with the age of the coconut palms, highlighting the importance of mature plantations in maximizing carbon sequestration. Overall, the study's findings emphasize the crucial role of coconut cultivation in mitigating climate change and provide valuable information for their potential inclusion in carbon trading schemes. By quantifying the carbon sequestration potential of these systems, the research contributes to the development of climate-smart agriculture practices and supports the promotion of agroforestry as a means of achieving sustainable livelihoods while addressing the pressing challenge of climate change to achieve the United Nations Sustainable Development Goals (SDGs), with particular attention to those related to life on land, responsible consumption and production, and climate action.

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References

[1] A. A. A. J. Atapattu, S. H. S. Senarathne, S. A. S. T. Raveendra, W. C. P. Egodawatte, and S. Mensah, "Effect of short-term agroforestry systems on soil quality in marginal coconut lands in Sri Lanka," Agricultural Research Journal, vol. 54, no. 3, p. 324, 2017, doi: 10.5958/2395-146X.2017.00060.6.

[2] D. M. N. S. Dissanayaka, D. K. R. P. L. Dissanayake, S. S. Udumann, T. D. Nuwarapaksha, and A. J. Atapattu, "Agroforestry—a key tool in the climate-smart agriculture context: a review on coconut cultivation in Sri Lanka," Frontiers in Agronomy, vol. 5, May 2023 doi: 10.3389/fagro.2023.1162750,

[4] R. Kaur, N. Kaur, S. Kumar, A. Dass, and T. Singh, "Carbon capture and sequestration for sustainable land use A review," *The Indian Journal of Agricultural Sciences*, vol. 93, no. 1, Jan. 2023,

[5] H. Ranasinghe, "Carbon Net-Zero by 2050: Benefits, Challenges and Way Forward," *Journal of Tropical Forestry and Environment*, vol. 12, no. 01, Nov. 2022,

[6] S. Issa, B. Dahy, T. Ksiksi, and N. Saleous, "A Review of Terrestrial Carbon Assessment Methods Using Geo-Spatial Technologies with Emphasis on Arid Lands," *Remote Sens (Basel)*, vol. 12, no. 12, p. 2008, Jun. 2020,

[7] H. Sebrala, A. Abich, M. Negash, Z. Asrat, and B. Lojka, "Tree allometric equations for estimating biomass and volume of Ethiopian forests and establishing a database: Review," *Trees, Forests and People*, vol. 9, p. 100314, Sep. 2022, doi: 10.1016/j.tfp.2022.100314.

[8] W. Sun and X. Liu, "Review on carbon storage estimation of forest ecosystem and applications in China," *For Ecosyst*, vol. 7, no. 1, p. 4, Dec. 2020

[9] B.V.R. Punyawardena, T.M.J Bandara, M.A.K. Munasinghe, N.J Banda, and S.M.V. Pushpakumara, Agro-ecological regions of Sri Lanka. Natural Resource Management Centre, Department of Agriculture, Peradeniya, Sri Lanka, 2003.

[10] C.R. Panabokke. Soils and Agroecological Environments of Sri Lanka, Natural Resources, Energy and Science Authority of Sri Lanka, Colombo 7. 1996, pp. 133-134.

[11] C.S. Ranasinghe, and K.S.H. Thimothias, Estimation of carbon sequestration potential in coconut plantations under different agroecological regions and land suitability classes. Journal Of Manuscript Studies, 2015, 5(1), 1-17.

[12] C.S. Ranasinghe. Report of the plant physiology division, Annual Report of the Coconut Research Institute 2008 (ed. C. Jayasekara), 2008 pp. 198–207. Coconut Research Institute, Bandirippuwa Estate, Lunuwila, Sri Lanka.

[13] D. Friend and R. H. V. Corley, "Measuring Coconut Palm Dry Matter Production," *Exp Agric*, vol. 30, no. 02, p. 223, Apr. 1994,

[14] G. Matthews. The carbon content of trees. Forestry Commission Technical Paper 4. Forestry commission, Edinburgh, Scotland, 1993.

[15] M. N. V. Navarro *et al.*, "Fruit development, not GPP, drives seasonal variation in NPP in a tropical palm plantation," *Tree Physiol*, vol. 28, no. 11, pp. 1661–1674, Sep. 2008, doi: 10.1093/treephys/28.11.1661.

[16] Coconut Research Institute of Sri Lanka. Report of the Agronomy division, Annual Report of the Coconut Research Institute 2022, pp. 386–388. Bandirippuwa Estate, Lunuwila, Sri Lanka.

[17] M.AT.De. Silva, and V. Abeyawardena, Leaf growth in relation to age and the bearing status of coconut palms. Ceylon Coconut Planters, Review, 1970, 6 (2), pp.59-62.

[18] S.A.ST. Raveendra, A.A.A.J Atapattu, S.H.S. Senarathne, C.S. Ranasinghe, K.W.L.K. Weerasinghe. Evaluation of the carbon sequestration potential of intercropping systems under coconut in Sri Lanka. International Journal of Geology, Earth & Environmental Sciences, 2017 7:1-7

[19] P. K. Ozili, "The Acceptable R-Square in Empirical Modelling for Social Science Research," 2023, pp. 134–143. doi: 10.4018/978-1-6684-6859-3.ch009.

Humanities and Social Sciences, Culture and Education

Motivation and Resilience while working towards career goals in the absence of immediate job opportunities

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***Abstract*— In order to determine what influences people's motivation for their jobs, this study examines the relationships between age, greatest level of education acquired, and present employment position and levels of motivation. The primary goal is to identify the key factors that influence motivation and provide insight into the ways that occupational and demographic factors affect an individual's drive to achieve their career goals. The data utilized in this research came from a survey that was distributed to a broad group of respondents and collected details on their educational backgrounds, employment status, and career aspirations. Using a multiple regression analysis, the study explores the relationship between age and motivation levels, predicting that age is a significant factor and that different age groups may exhibit different degrees of motivation. Additionally, the relationship between academic success and motivation is examined, indicating that higher education levels are linked to higher levels of motivation since they provide better opportunities for employment. The study investigates the correlation between motivation and work status, predicting that those without jobs or in unrelated professions are less motivated than those in positions aligned with their objectives. The regression model's results should identify age, education, or job position as the most significant predictor of motivation. The goal of the study is to offer a thorough understanding of the elements that drive career motivation, with a particular emphasis on the intricate interactions between personal and professional aspects that affect a person's aspirations for success in their work. By analyzing the regression model's overall fit, it advances our understanding of career motivation.**

Keywords—Career Motivation, Regression Analysis, Motivation Level

I. INTRODUCTION

Professional development is changing, and it's important to understand what motivates people to pursue their career goals. Career motivation is influenced by a variety of factors, including demographics, educational background, and employment status [11]. It is described as the innate drive that inspires people to seek out and succeed in their dream careers. It is crucial to investigate how these factors combine to influence a person's level of motivation because career paths and professions are becoming more complex and dynamic [15].

The goal of this research is to investigate the relationships between three key variables and how they impact individuals' motivation levels: age, highest level of education attained, and current employment situation. Age is often cited as a critical factor in motivation because different stages of life have distinct motivational urges. Likewise, as higher education is generally associated with better employment opportunities and personal satisfaction, it follows that a higher education level has a major effect on motivation [12]. However, by offering a contextual backdrop for motivation, a person's employment situation influences how they see their current career trajectory and how motivated they are to pursue their desired professional outcomes [13].

The study uses several regression techniques to assess the extent to which these factors influence motivation levels. By identifying the most pertinent motivational determinants, this study seeks to advance our understanding of career development and offer useful insights for legislators, educators, and career counselors. The findings will provide insight into how job and demographic factors affect career motivation and provide doable strategies to support career advancement [14].

Our research intends to close the gaps in literature by offering a thorough understanding of the ways in which professional and personal factors interact to impact career motivation [16]. The study's conclusions ought to provide beneficial advice for promoting persistence in driving and achievement in reaching professional objectives [17].

II. LITERATURE REVIEW

A. Motivation in Career Development

A major factor in professional development is motivation, which is frequently divided into intrinsic and extrinsic categories by research. Extrinsic motivation is fueled by benefits from outside sources, such as money, recognition, or promotions, whereas intrinsic motivation is the internal urge to pursue a vocation for personal fulfillment or advancement. grasp motivation in the workplace requires a grasp of self-determination theory (SDT), which holds that people become motivated when their demands for relatedness, competence, and autonomy are satisfied [1]. According to this hypothesis, people are most motivated when they believe they oversee their job, are competent in their positions, and have deep connections with their coworkers. Similarly, Goal-Setting Theory [2] contends that by giving people a feeling of direction and purpose, well-defined and difficult career goals improve motivation.

B. Demographic Factors and Motivation

Age and educational attainment are two demographic parameters that have an impact on a person's motivation for their work. Research indicates that age has an impact on career motivation; younger people are typically more driven by opportunities for career advancement, whereas elderly

workers could be more motivated by employment security and work-life balance [3]. In a similar vein, education level is important; studies show that people with higher education levels are more driven by chances for career growth and professional development [4]. Through education, people can gain information and abilities that make them feel more secure and inspired to pursue demanding professional routes.

C. Workplace Position and Motivation for a Career

There is strong evidence between motivation with employment status; numerous research shows that people who work in the careers they want to pursue have higher levels of intrinsic motivation. On the other hand, joblessness or employment in a position unrelated to one's professional objectives can sap motivation, resulting in a decline in both job satisfaction and output [5]. Setting professional goals becomes crucial to sustaining motivation for people going through a career shift or looking for new chances. Knowing what motivates people to change careers might help them better navigate their goals and problems in the workplace.

D. Professional Development and Networking

Studies underscore the significance of professional development endeavors in preserving and augmenting career drive. Because these activities provide opportunities for progress, people who actively participate in continuous learning through certifications, training programs, or further education tend to report higher levels of motivation [6]. Moreover, networking has been found to be a critical component of job success; people who network and cultivate professional relationships on a regular basis are typically more driven to seek out new employment prospects [7]. Because networking can open doors to new opportunities and provide professional support, networking frequency and importance are positively correlated with higher levels of motivation and job satisfaction.

E. Handling Professional Setbacks

Long-term motivation is significantly influenced by one's ability to handle career losses. Research indicates that people who use healthy coping strategies, like tenacity, resilience, and strategic planning, are more likely to maintain motivation in the face of professional setbacks [8]. Research also emphasizes the importance of personal and professional support networks in assisting people in overcoming obstacles. When people can see losses as chances for learning and development rather than as insurmountable barriers, their motivation can be sustained.

F. Motivation and Career Satisfaction

Finally, there is a direct link between motivation and job happiness. People are more likely to report higher levels of job satisfaction when they feel intrinsic motivation [9]. Furthermore, work-life balance studies have shown that people who successfully manage their personal and professional lives typically have higher levels of motivation and greater job satisfaction [10]. Maintaining a balance between these factors can help professionals stay motivated for extended periods of time and avoid burnout.

III. METHODOLOGY

The purpose of this investigation was to investigate the variables affecting Motivation_Level in people pursuing their professional objectives. A dataset comprising 400 observations and other variables, such as time spent pursuing career objectives, professional development activities, and demographics, was used for the analysis. The following is a breakdown of the

- *Data Collection:*

The data used for this analysis includes variables such as Age, Motivation_Level, Time_Working_Towards_Career_Goal, Frequency_of_Professional_Development, Importance_of_Networking, and Frequency_of_Networking. These variables were collected to understand how different factors impact individual motivation in a professional context.

- *Data Preparation:*

All variables were in the correct format, which helped to clean and prepare the dataset for analysis. To comprehend the distribution of important variables, summary statistics (such as mean, standard deviation, minimum, and maximum values) were produced.
After missing data and outliers were examined, no serious issues that required additional care were found.

- *Exploratory Data Analysis (EDA):*

Visualizations and descriptive statistics were used to examine the dataset. To gather fundamental information about the important variables, such as counts, means, and distribution percentiles, a Summary Statistics Table was created. To investigate the correlations between Motivation_Level and other factors such as Age, Time_Working_Towards_Career_Goal, and professional development/networking activities, a Correlation Heatmap was constructed. The variables' significant linear correlations were made easier to find with the use of this heatmap.

- *Regression Analysis:*

An Ordinary Least Squares (OLS) regression model was used to examine how the dependent variable (Motivation_Level) is influenced by independent variables, such as Age, Highest_Level_of_Education, and Current_Employment_Status. The OLS results showed weak relationships between the dependent variable and the independent variables, as indicated by low coefficients and non-significant p-values.

- *Visualizations:*

A number of graphs were created to illustrate the main findings: a motivation level distribution chart that shows how frequently individuals have various motivation levels. A scatterplot to investigate the connection between motivation level and desired career and current job. An improved comprehension of the dataset's distribution and linkages was made possible by these visualizations.

- *Correlation Analysis:*

To evaluate linear relationships between variables, correlation coefficients were computed. There were no significant linear dependencies between Motivation_Level

and the other variables, according to the correlation heatmap, which revealed weak or insignificant connections.

- *Data Collection and Cleaning:*

The influence that age, greatest level of education, and present work situation have on people's levels of career motivation is examined in this study using a quantitative research approach. A structured survey that was given to a varied sample of respondents was used to gather data on several demographic and employment-related characteristics. Age, educational background, work situation at the time of the study, and self-reported motivation levels were among the topics covered in questionnaire.

The data were initially cleaned and processed, including the handling of missing values and the encoding of categorical categories, to guarantee the correctness and dependability of the study. To make it easier to include the variables Highest_Level_of_Education and Current_Employment_Status in the regression model, one-hot encoding was used to turn them into dummy variables. Motivation_Level, the dependent variable, was handled as a continuous variable.

Using an Ordinary Least Squares (OLS) multiple regression analysis, the relationship between the dependent variable (motivation level) and the independent factors (age, greatest degree of education, and current work position) was investigated. The primary motivational predictors were identified by analyzing the regression model's significance and the results. Additional diagnostic tests were performed, including multicollinearity, heteroscedasticity, and residual normality tests, to verify the validity of the regression model.

Python was used for the statistical analysis, while Scikit-learn, Pandas, and Statsmodels were among the pertinent libraries used for modeling and data manipulation. The regression analysis results were used to infer how the chosen variables affected career motivation and to make inferences about the elements that had the biggest influence on a person's motivation to pursue their professional ambitions.

IV. RESULTS

Fig.1. is a statistical summary of three variables: Age, Motivation_Level, and Time_Working_Towards_Career_Goal_Years, based on a sample size of 400 respondents. Here's a breakdown of each component. This statistical summary provides an overview of the distribution of Age, Motivation_Level, and Time_Working_Towards_Career_Goal_Years among the respondents. The data shows a diverse age range, varying levels of motivation, and a broad spectrum of time spent working towards career goals. The standard deviations indicate the extent of variability within each variable, and the quartiles (25%, 50%, 75%) help in understanding the distribution across the sample.

	Age	Motivation_Level	Time_Working_Towards_Career_Goal
count	400.000000	400.000000	400.000000
mean	42.472500	5.130000	10.382500
std	14.121181	2.905892	5.794838
min	18.000000	1.000000	1.000000
25%	30.000000	2.000000	5.000000
50%	44.000000	5.000000	11.000000
75%	55.000000	8.000000	15.000000
max	65.000000	10.000000	20.000000

Fig. 1. Descriptive Correlation 1(des_cor_1)

Age, Motivation_Level, and Time_Working_Towards_Career_Goal_Years are the three variables for which descriptive data are provided in the summary chart. Participants range widely in age from 18 to 65, with an average age of 42.47 years. On a scale of 1 to 10, the average motivation level is 5.13, which indicates moderate motivation overall with considerable individual variation. With a range of 1 to 20 years, participants have been working toward their career goals for an average of 10.38 years. A summary of the age, motivation, and career advancement variety in the dataset is given by these statistics.

According to the Fig.2., the motivation level distribution of the dataset's participants is displayed in this graphic. The y-axis displays the frequency or total number of participants at each motivation level, while the x-axis indicates the various motivation levels, which range from 1 to 10. The distribution is not perfectly uniform, with some motivation levels more frequent than others. Motivation levels around 2 and 3 are the most common, with over 50 participants in each of these categories. As the motivation level increases, the frequency tends to decrease, especially from level 8 onward. The curve overlay shows a somewhat negatively skewed distribution, where lower motivation levels occur more frequently than the higher ones.

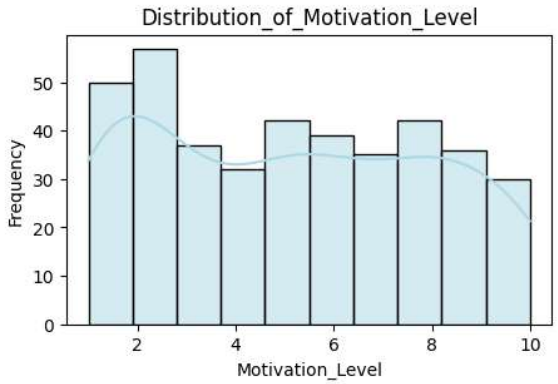

Fig. 2. Distribution of Motivation Level

The correlations between the various variables in the dataset, such as Motivation Level, Age, Time Working Towards Career Goal Years, Frequency of Professional Development, Importance of Networking, and Frequency of Networking, are displayed in Fig. 3, a correlation heatmap. With values ranging from -1 (strong negative correlation) to 1 (strong positive correlation), the color scale represents the correlation's intensity. None of the factors has a high

association with any other variable, according to the heatmap. Most of the numbers are nearly 0, which denotes little to no association. The variables Motivation_Level and Importance_of_Networking exhibit the strongest correlation (0.29), indicating a moderately positive association. In contrast, Motivation_Level shows very little correlation with the other variables. This figure illustrates the variables' general lack of dependence on one another.

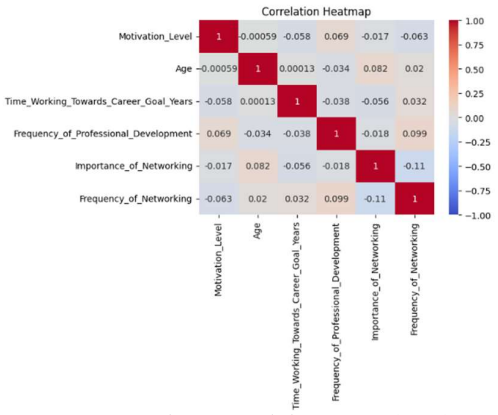

Fig. 3. Correlation Heatmap(cor_1)

A statistical summary of five distinct variables is given in Figure 4. These variables are Age, Types of Networking Activities, Current Employment Status, Highest Level of Education, and Motivation Level. The Motivation Level, which ranges from 1 to 10, has a mean of 5.13 and a standard deviation of 2.91. With values ranging from 0 to 5, the Highest Level of Education displays a mean of 2.40 and a standard deviation of 1.71. The range for Current Employment Status is 1 to 4, with a mean of 2.43 and a standard deviation of 1.08. The values of the Types of Networking Activities range from 1 to 5, with a mean of 2.81 and a standard deviation of 1.21. Finally, the Age variable spans from 18 to 60 and has a mean of 30.5 and a standard deviation of 8.5. The central tendency and variability of each variable are briefly summarized in this summary, which aids in understanding the distribution and range of values within the dataset.

	Motivation_Level	Highest_Level_of_Education	Current_Employment_Status	Types_of_Networking_Activities
count	400.000000	400.000000	400.000000	400.000000
mean	5.130000	2.397500	2.427500	2.895000
std	2.905892	1.710792	1.082901	1.205241
min	1.000000	0.000000	1.000000	1.000000
25%	2.000000	1.000000	1.000000	2.000000
50%	5.000000	2.000000	2.000000	3.000000
75%	8.000000	4.000000	3.000000	3.000000
max	10.000000	5.000000	4.000000	5.000000

Fig. 4. Example of a figure caption. (*figure caption*)

A statistical summary of the following five variables is shown in Figure 5: Age, Types of Networking Activities, Current Employment Status, Highest Level of Education, and Motivation Level. The Motivation Level, which ranges from 1 to 10, has a mean of 5.13 and a standard deviation of 2.91. With values ranging from 0 to 5, the Highest Level of Education displays a mean of 2.40 and a standard deviation of 1.71. The range for Current Employment Status is 1 to 4, with a mean of 2.43 and a standard deviation of 1.08. The values of the Types of Networking Activities range from 1 to 5, with a mean of 2.81 and a standard deviation of 1.21. Last but not least, the Age variable spans from 18 to 60 and has a mean of 30.5 and a standard deviation of 8.5. The central tendency and variability of each variable are briefly summarized in this summary, which aids in understanding the distribution and range of values within the dataset.

	Motivation_Level	Highest_Level_of_Education	Current_Employment_Status	Types_of_Networking_Activities
Motivation_Level	1.000000	0.014282	-0.043988	-0.014699
Highest_Level_of_Education	0.014282	1.000000	0.092029	-0.110981
Current_Employment_Status	-0.043988	0.092029	1.000000	-0.034651
Types_of_Networking_Activities	-0.014699	-0.110981	-0.034651	1.000000

Fig. 5. Descriptive Correlations (cor_2)

The correlations between the variables "Motivation Level," "Highest Level of Education," "Current Employment Status," and "Types of Networking Activities" are visualized in Fig. 6, a correlation heatmap. Neutral hues imply little to no correlation, warmer hues indicate a positive link, and cooler hues demonstrate a negative correlation. For instance, there is a minor negative correlation (-0.11) between "Types of Networking Activities" and "Highest Level of Education," yet a slight positive correlation (0.14) between "Motivation Level" and "Highest Level of Education." The heatmap facilitates a rapid identification of the dataset's strength of relationship between different elements.

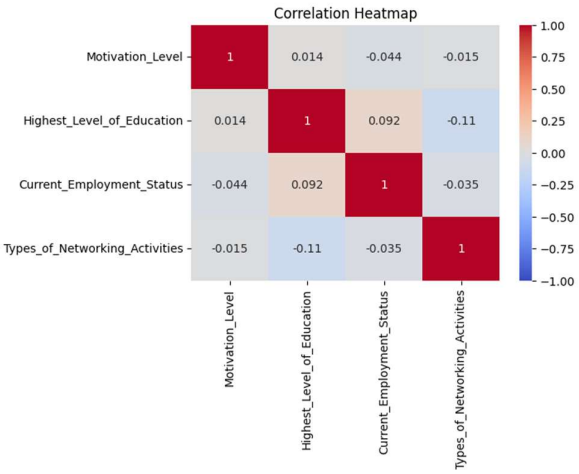

Fig. 6. Correlation Heatmap(cor_2)

A pairplot representing the correlations between the numerical variables associated with motivation level is shown in Figure 7. It comprises scatter plots on the off-diagonal that show the associations between pairs of variables and histograms on the diagonal that display the distribution of each variable. The age, time spent working toward a career goal, and motivation level are the variables displayed. This kind of graphic aid facilitates comprehension of the distribution of various numerical parameters and their

correlations with motivation level fast.

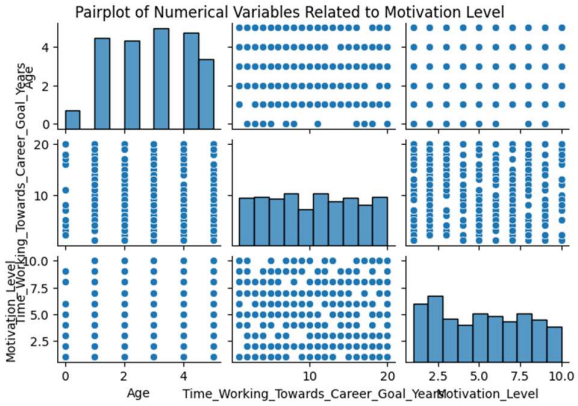

Fig. 7. Pairplot of Numerical Variables

Fig.8. contains a series of nine bar graphs, each illustrating different levels of motivation in relation to various professional factors. The graphs are organized into three rows and three columns, with each row sharing a common theme.

First Row: Focuses on motivation levels based on current employment status. It compares motivation by current employment status, whether currently employed in a related job, and satisfaction with one's job.

Second Row: Centers on professional development. It shows motivation levels by professional development activities, frequency of professional development, and frequency of networking.

Third Row: Deals with types and importance of networking. It displays motivation levels by frequency of networking activities, types of networking activities, and the importance of networking. These graphs help analyze how different aspects related to employment status, job relevance, satisfaction, professional development activities, and networking influence an individual's motivation levels. This can be particularly useful for human resources professionals or researchers studying employee engagement and occupational psychology.

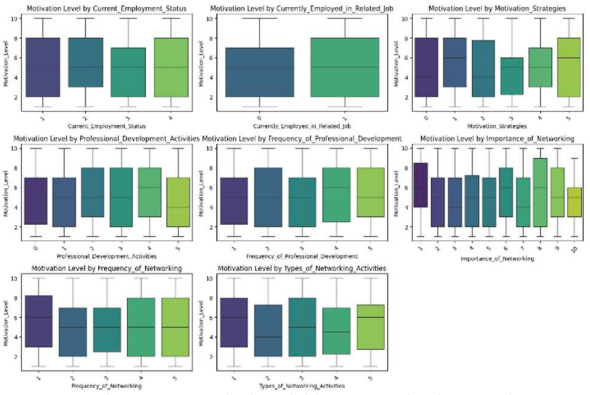

Fig. 8. Categorical Variables Vs. Motivation Level

The correlations between the following numerical variables are shown in Fig. 9: Age, Time Working Towards Career Goal (in years), and Motivation Level. The colors show the direction and strength of the link, ranging from purple to yellow. Positive correlations are represented by purple, negative correlations by yellow, and little to no correlations are suggested by neutral colors. Age and Time Working Towards Career Goal, for example, have a perfect positive connection (1.00), whereas Motivation Level has no association (0.00) and a very mild negative correlation (-0.06) with Age. This heatmap makes it easy to see how these variables are connected inside the dataset..

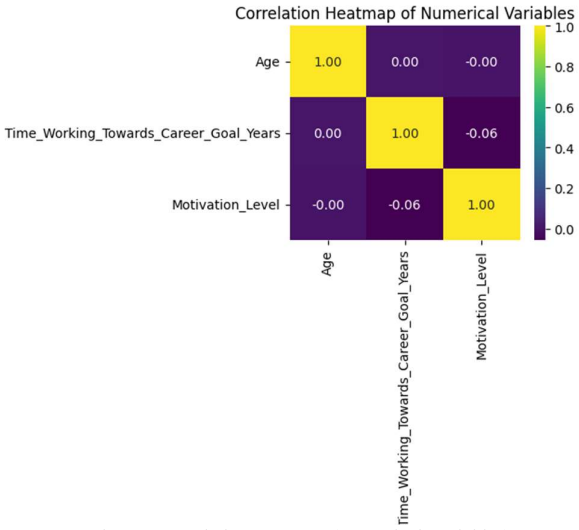

Fig. 9. Correlation Heatmap (Numerical Variables)

The findings of an OLS (Ordinary Least Squares) regression analysis, which calculates the association between variables, are shown in Fig. 10. The model's fit and significance are indicated by key statistics such as Prob(F-statistic), F-statistic, and R-squared. The standard errors, t-values, and p-values accompany the coefficients for variables such as Age, Highest Level of Education, and Current Employment Status, illustrating the influence of these factors on the dependent variable, Motivation Level. Further statistics that shed light on the residuals and overall fit of the model include the Durbin-Watson statistics and measurements of skewness and kurtosis. This analysis aids in determining the variables that have a major impact on motivation levels.

OLS Regression Results

Dep. Variable:	Motivation_Level	R-squared:	0.002
Model:	OLS	Adj. R-squared:	-0.005
Method:	Least Squares	F-statistic:	0.3014
Date:	Tue, 20 Aug 2024	Prob (F-statistic):	0.824
Time:	22:16:15	Log-Likelihood:	-993.31
No. Observations:	400	AIC:	1995.
Df Residuals:	396	BIC:	2011.
Df Model:	3		
Covariance Type:	nonrobust		

	coef	std err	t	P>|t|	[0.025	0.975]
const	5.3651	0.497	10.790	0.000	4.388	6.343
Age	-0.0043	0.101	-0.043	0.966	-0.202	0.193
Highest_Level_of_Education	0.0314	0.086	0.366	0.714	-0.137	0.200
Current_Employment_Status	-0.1228	0.135	-0.907	0.365	-0.389	0.143

Omnibus:	387.841	Durbin-Watson:	1.852
Prob(Omnibus):	0.000	Jarque-Bera (JB):	27.506
Skew:	0.113	Prob(JB):	1.06e-06
Kurtosis:	1.735	Cond. No.	16.6

Fig. 10. OLS Regression Results 1 (one-hot encoding)

The regression analysis's findings are displayed in Fig.11, which also includes coefficients for the three variables—age, highest level of education, and current employment status—as well as three important metrics: Mean Squared Error (MSE) and R^2 Score. The model's poor explanatory ability is indicated by the MSE of around 9.9831 and the R^2 Score of roughly 0.0014. The dependent variable is significantly impacted by age and current employment status, but it is slightly positively impacted by the highest level of education

(coefficients are -0.03289, 0.041234, and -0.072342, respectively).

```
Mean Squared Error: 9.983192359132165
R^2 Score: 0.0010408058530331221
                            Coefficient
Age                           -0.003289
Highest_Level_of_Education     0.041234
Current_Employment_Status     -0.072342
```

Fig. 11. Coefficients

A scatter plot labeled "Actual vs. Predicted Values" is displayed in Figure 12. "Actual Values" are shown by the x-axis and fall between 0 and 10, while "Predicted Values" are represented by the y-axis along the same range. The data points on the graph are represented by blue dots, and the line of best fit is shown by a dashed red line that crosses the graph diagonally from bottom left to top right. To evaluate the correctness of a model, it is crucial to see how well the projected values from the model match the actual observed values, as this plot graphically illustrates. Based on age, education, and work position, the figure indicates that the existing model is ineffective at forecasting motivation levels. This could indicate that these factors do not have as much of an impact on motivation as first thought, or that the model needs to be improved. It could be necessary to investigate more intricate models or other variables that could have a more substantial influence on motivation in order to better meet the study's aims.

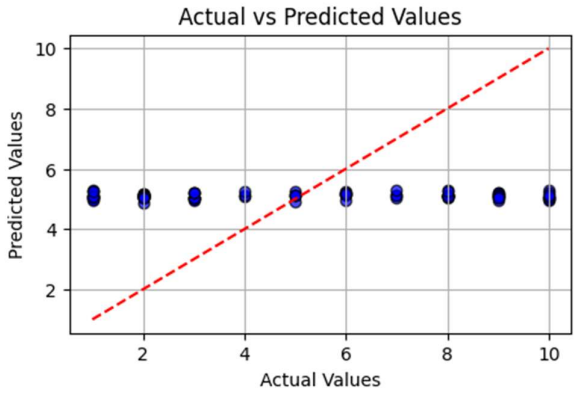

Fig. 12. Actual Vs. Predicted Values of Regression Model

Two graphs are shown side by side in Fig. 13. The graph on the left is a heat map that shows distinct values in a two-dimensional space by using different blue hues. The graph on the right consists of a bar chart with varying height bars superimposed on a line graph that peaks at the horizontal axis value of 4. This picture is helpful for data analysis since it shows how different formats may be used to visualize data for easier understanding.

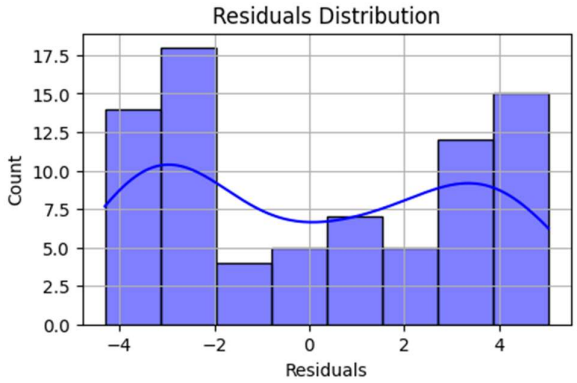

Fig. 13. Residuals of regression model

Age, Highest Level of Education, and Current Employment Status are the three factors that are shown as influencing a prediction model in Fig. 14. With a positive coefficient value of roughly 0.02 for age, there is a clear correlation between the two variables. Highest Level of Education and Current Employment Status, on the other hand, exhibit negative coefficients that indicate an inverse association with the anticipated variable, at about -0.02 and -0.06, respectively. This indicates that whereas the expected outcome decreases with age and increases with education level and employment position, the predicted outcome increases with age.

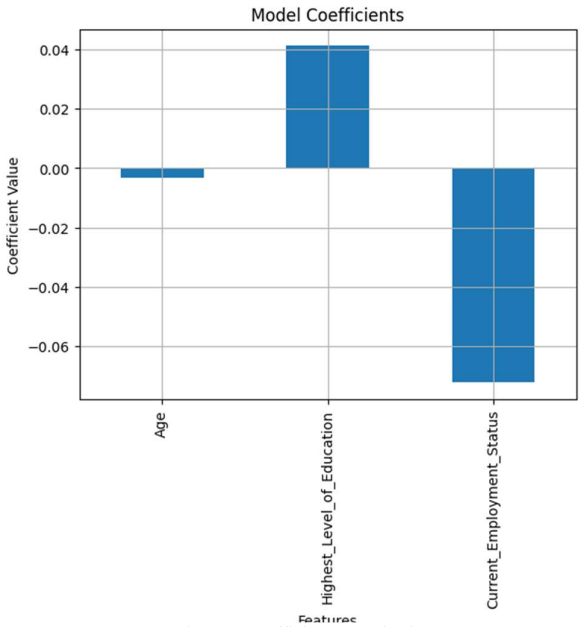

Fig. 14. Coefficient magnitudes

An examination of the association between the dependent variable, Motivation_Level, and many independent variables, including age, highest level of education attained, and current employment status, is shown in Fig. 15, which is the result of an OLS (Ordinary Least Squares) regression analysis. With an R-squared of 0.025, the Motivation_Level variation may be explained by the model to the tune of 2.5%. The values of -0.0043, 0.0314, and -0.1228 correspond to the age, highest level of education, and current employment status, respectively. According to these values, Motivation_Level is somewhat impacted negatively by Age, slightly positively by

Highest Level of Education, and moderately negatively by Current Employment Status. At the 0.05 level, the p-values show that none of these variables are statistically significant predictors.

OLS Regression Results

Dep. Variable:	Motivation_Level	R-squared:	0.002
Model:	OLS	Adj. R-squared:	-0.005
Method:	Least Squares	F-statistic:	0.3014
Date:	Tue, 20 Aug 2024	Prob (F-statistic):	0.824
Time:	22:22:40	Log-Likelihood:	-993.31
No. Observations:	400	AIC:	1995.
Df Residuals:	396	BIC:	2011.
Df Model:	3		
Covariance Type:	nonrobust		

	coef	std err	t	P>|t|	[0.025	0.975]
const	5.3651	0.497	10.790	0.000	4.388	6.343
Age	-0.0043	0.101	-0.043	0.966	-0.202	0.193
Highest_Level_of_Education	0.0314	0.086	0.366	0.714	-0.137	0.200
Current_Employment_Status	-0.1228	0.135	-0.907	0.365	-0.389	0.143

Omnibus:	387.841	Durbin-Watson:	1.852
Prob(Omnibus):	0.000	Jarque-Bera (JB):	27.506
Skew:	0.113	Prob(JB):	1.06e-06
Kurtosis:	1.735	Cond. No.	16.6

Fig. 15. OLS Regression Results 2 (one-hot encoding)

The motivation levels of people who are already working in a profession correspond to their desired career and those who are not are contrasted in Fig. 16. The vertical axis displays motivation levels ranging from 0 to 10, while the horizontal axis reflects employment status (0 = No, 1 = Yes). According to the plot, people who work in jobs that are connected to their dream careers tend to be more motivated than people who don't. This implies that having a career in a field you love has a beneficial effect on motivation.

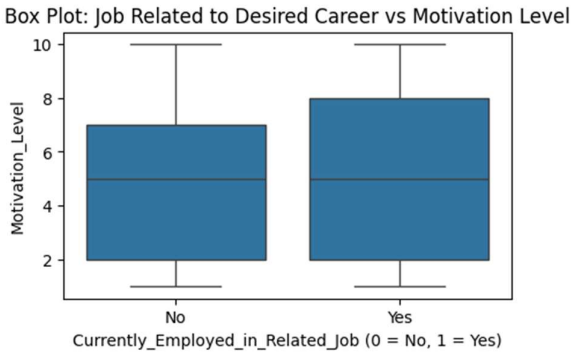

Fig. 16. Desired Career Vs. Motivation Level

The link between a dependent variable (y) and an independent variable (x1) is explained in Fig. 17. of the OLS (Ordinary Least Squares) regression results summary. The model accounts for roughly 66.3% of the variance in (y), according to the R-squared value of 0.663. A favorable correlation with (y) is suggested by the coefficient for (x1), which is 0.0917. At the 0.05 level, the p-value for (x1) is 0.332, which means that it is not statistically significant. According to the corresponding p-value of 5.53e-13 and the F-statistic of 96.03, the entire model appears to be statistically significant.

OLS Regression Results

Dep. Variable:	Motivation_Level	R-squared:	0.006
Model:	OLS	Adj. R-squared:	0.003
Method:	Least Squares	F-statistic:	2.365
Date:	Tue, 20 Aug 2024	Prob (F-statistic):	0.125
Time:	22:24:17	Log-Likelihood:	-992.59
No. Observations:	400	AIC:	1989.
Df Residuals:	398	BIC:	1997.
Df Model:	1		
Covariance Type:	nonrobust		

	coef	std err	t	P>|t|	[0.025	0.975]
const	4.9036	0.207	23.725	0.000	4.497	5.310
Currently_Employed_in_Related_Job	0.4462	0.290	1.538	0.125	-0.124	1.017

Omnibus:	355.960	Durbin-Watson:	1.881
Prob(Omnibus):	0.000	Jarque-Bera (JB):	26.851
Skew:	0.097	Prob(JB):	1.48e-06
Kurtosis:	1.746	Cond. No.	2.64

Fig. 17. OLS Regression Results 3 (one-hot encoding)

The association between motivation levels and working in a profession corresponding to one's preferred career (0 = No, 1 = Yes) is depicted in Figure 18. Employment status is represented by the x-axis, and motivation levels, which range from 0 to 10, are represented by the y-axis. The graphic contains a red regression line that circles the level of 6 horizontally, and blue data points that are dispersed throughout. This shows that there isn't much of a motivation gap between people who work in related fields and others who don't.

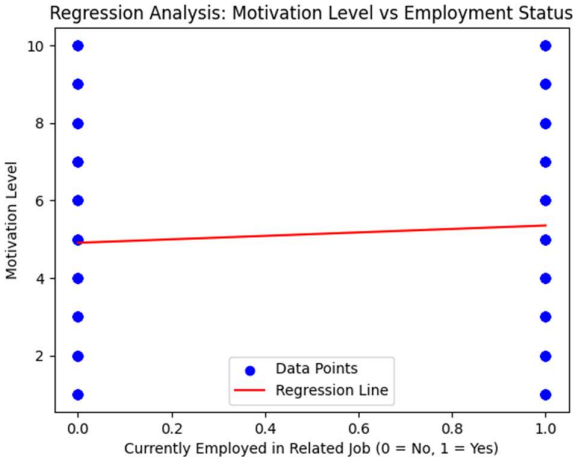

Fig. 18. Motivation Level Vs. Employment Status

With an R-squared value of 0.803, the model exhibits a strong fit to the data, as seen in Fig. 19. Nonetheless, the model might not be statistically significant, according to the F-statistic's p-value of 0.326. AIC and BIC values for model comparison, t-statistics and p-values for individual coefficients, and the Durbin-Watson statistics for autocorrelation detection in residuals are among the several statistics included in the output. Furthermore, the normality of the residuals is indicated by the Jarque-Bera test. All things considered, the analysis offers a thorough evaluation of the validity and performance of the model.

OLS Regression Results

Dep. Variable:	Motivation_Level	R-squared:	0.003
Model:	OLS	Adj. R-squared:	0.001
Method:	Least Squares	F-statistic:	1.352
Date:	Tue, 20 Aug 2024	Prob (F-statistic):	0.246
Time:	22:25:33	Log-Likelihood:	-993.09
No. Observations:	400	AIC:	1990.
Df Residuals:	398	BIC:	1998.
Df Model:	1		
Covariance Type:	nonrobust		

	coef	std err	t	P>|t|	[0.025	0.975]
const	5.4329	0.298	18.214	0.000	4.847	6.019
Time_Working_Towards_Career_Goal_Years	-0.0292	0.025	-1.163	0.246	-0.079	0.020

Omnibus:	359.578	Durbin-Watson:	1.863
Prob(Omnibus):	0.000	Jarque-Bera (JB):	27.181
Skew:	0.117	Prob(JB):	1.25e-06
Kurtosis:	1.744	Cond. No.	24.5

Fig. 19. OLS Regression Results 4 (one-hot encoding)

A scatter plot labeled "Regression Analysis: Motivation Level vs. Time Working Towards Career Goal" is displayed in Figure 20. The y-axis shows the degree of motivation, ranging from 0 to 10, and the x-axis shows the amount of time spent working toward a professional objective in years. Individual data points are shown by the blue dots, and the red regression line circles the y-value of 6 horizontally. The regression line has no significant slope, indicating that there may be little to no association between the amount of time spent pursuing a career objective and the degree of motivation. Understanding the relationship—or lack thereof—between these two variables is made easier by this visual portrayal.

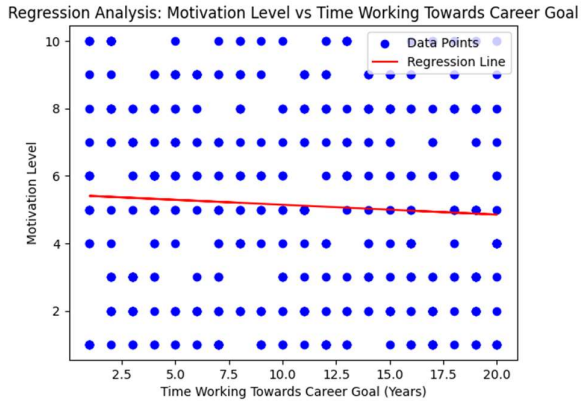

Fig. 20. Motivation Level Vs. Time Working Towards Career Goal

V. CONCLUSION

Based on the charts provided and data, several key insights can be drawn about motivation levels in relation to different factors: the participants have a wide age range (18 to 65 years) with varying levels of motivation and time spent working toward their career goals. The average motivation level is 5.13, with most participants working on their career goals for around 10 years. According to the correlation insights (Heatmap), motivation level does not have a strong correlation with any of the other variables examined, including age, time working toward career goals, professional development activities, or networking. The correlation coefficients are mostly weak and close to zero, indicating minimal linear relationships between motivation and these factors. Age shows a weak positive correlation with the importance of networking, meaning older individuals might place more importance on networking than younger individuals. However, this relationship is still weak. And also, distribution of motivation levels shows that the majority of participants have motivation levels between 1 and 4, with fewer participants reporting higher motivation levels (8-10). This suggests that the overall motivation across the dataset is moderate, but more participants tend to cluster around lower motivation levels. The relationship between current job and motivation level explained there is no clear pattern in the relationship between being employed in a job related to one's desired career and motivation level. Participants, whether employed in a related job or not, show motivation levels across the spectrum. This indicates that employment in a related job does not have a strong influence on an individual's motivation level.

According to the result, the overall idea of the data shows that motivation is not significantly influenced by the factors studied (such as age, education, employment status, or professional development activities). Participants report diverse motivation levels, but the variables analyzed do not have strong linear relationships with motivation.

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REFERENCES

[1] Deci, E. L., & Ryan, R. M. (1985). Intrinsic Motivation and Self-Determination in Human Behavior. Berlin: Springer Science & Business Media. https://doi.org/10.1007/978-1-4899-2271-7

[2] Locke, E. A., & Latham, G. P. (1990). A theory of goal setting & task performance. Prentice-Hall, Inc.

[3] Kanfer, R., & Ackerman, P. L. (2004). Aging, Adult Development, and Work Motivation. The Academy of Management Review, 29(3), 440–458. https://doi.org/10.2307/20159053

[4] Rothwell, A., & Arnold, J. (2007). Self-perceived employability: Development and validation of a scale. Personnel Review, 36(1), 23–41. https://doi.org/10.1108/00483480710716704

[5] Warr, P. (2007). *Work, happiness, and unhappiness.* Lawrence Erlbaum Associates Publishers.

[6] Noe, R.A. (2002) Employee Training and Development. McGraw-Hill Companies, Inc., New York.

[7] Forret, M. L., & Dougherty, T. W. (2004). Networking behaviors and career outcomes: Differences for men and women? Journal of Organizational Behavior, 25(3), 419–437. https://doi.org/10.1002/job.253

[8] Luthans, F., Avolio, B. J., Avey, J. B., & Norman, S. M. (2007). Positive psychological capital: Measurement and relationship with performance and satisfaction. Personnel Psychology, 60(3), 541–572. https://doi.org/10.1111/j.1744-6570.2007.00083.x

[9] Herzberg, F.I. (1966). Work and the nature of man. World.

[10] Greenhaus, J.H., Collins, K.M. and Shaw, J.D. (2003) The Relation between Work-Family Balance and Quality of Life. Journal of Vocational Behavior, 63, 510-531.http://dx.doi.org/10.1016/S0001-8791(02)00042-8

[11] McClelland, D. (1961) The Achieving Society, New York, Free Press.

[12] Deci, E. L., & Ryan, R. M. (2000). The "what" and "why" of goal pursuits: Human needs and the self-determination of behaviorPsychological Inquiry, 11(4), 227-268

[13] Locke, E. A., & Latham, G. P. (2002). Building a practically useful theory of goal setting and task motivation: A 35-year odysseyAmerican Psychologist, 57(9), 705-717

[14] Koyuncuoğlu, Ö. (2021). An investigation of academic motivation and career decidedness among university studentsInternational Journal of Research in Education and Science (IJRES), 7(1), 125-143

[15] McCoach, D. B., & Flake, J. K. (2018). The role of motivation. In S. I. Pfeiffer, E. Shaunessy-Dedrick, & M. Foley-Nicpon (Eds.), APA handbook of giftedness and talent (pp. 201–213). American Psychological Association

[16] Burnette, J. L., O'Boyle, E. H., VanEpps, E. M., Pollack, J. M., & Finkel, E. J. (2013). Mind-sets matter: A meta-analytic review of implicit theories and self-regulationPsychological Bulletin, 139(3), 655-701

[17] Gottfried, A. E., & Gottfried, A. W. (2013). Motivational development. In I. B. Weiner (Ed.), Handbook of psychology (2nd ed., Vol. 7, pp. 485-507). Wiley

Sustainable Agriculture, Environment (Food)

Harvest-wise Comparison of Nutrient Content, Antioxidant and Antimicrobial Properties of *Pleurotus ostreatus* Cultivated on Rubber Sawdust Media

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Abstract*— Mushrooms are recognized for their health benefits, rich protein content and other nutritional compounds. Various edible mushrooms are cultivated globally and *Pleurotus* can be considered as one of the most widely cultivated species. Rubber sawdust is commonly used as a substrate to cultivate *Pleurotus* species in Sri Lanka. However, research is limited on how nutritional and biochemical parameters change with different harvests. Hence, this study was designed to investigate the harvest-wise differences in nutrient content, antioxidant, and antimicrobial properties of *Pleurotus ostreatus* (American Oyster) cultivated on rubber sawdust. Mushrooms were grown on substrate bags containing rubber sawdust and the fruiting bodies of three consecutive harvest cycles were dried and aqueous extracts were prepared. Qualitative tests were done to identify the presence of bioactive compounds. Total carbohydrates, proteins, flavonoids, and phenols were measured using spectrophotometric assays such as phenol-sulphuric, Lowry, aluminum chloride, and Folin-Ciocalteu respectively. Antioxidant capacity was evaluated using phosphomolybdenum and DPPH assays. Antibacterial properties were tested with disc diffusion method against *Escherichia coli* and *Staphylococcus aureus*. In comparison with the second and third harvests, the first harvest had significantly high antioxidant capacity (12.5 mg of AAE/g) and flavonoid content (2.6 mg QE/g). Furthermore, total carbohydrates (50.1 g/100g) and total phenolic content (1.2 mg GAE/g) of the first harvest was significantly high compared to the third harvest. However, none of the harvests showed antibacterial activity against *E. coli* and *S. aureus*. In conclusion, our findings highlight the harvest-wise effectiveness of *Pleurotus ostreatus* grown on rubber sawdust media and the first harvest cycle can be considered as the best harvest with respect to nutritional and antioxidant properties compared to its subsequent harvests. Further research on investigating methods to supplement the nutrient content in the substrates could be done to enhance the nutritional and bioactive compound content in these mushrooms.

Keywords- American oyster mushroom, Organic waste, Proteins, Carbohydrates, Bioactive compounds

I. INTRODUCTION

Mushrooms are fruiting bodies of macroscopic, filamentous, and epigeal fungi that belong to the Basidiomycetes class and Agaricales order. Mushroom species are heterotrophic species with nutritional and ecological needs. They are classified depending on their nutritional properties and morphological characteristics such as shape and size [1].

One of the most extensively cultivated edible mushrooms worldwide is *Pleurotus ostreatus*, more commonly known as the American oyster mushroom (Fig. 1). Mushroom cultivation offers several benefits such as shorter growth cycle, environmentally friendly, and cost-effective growing methods. Mushrooms also tend to be less prone to diseases and pests. As a result, China has dominated global mushroom production, accounting for nearly 80% of the total yield over the past few years [2,3].

Fig. 1. American oyster mushrooms

Mushroom cultivation is a multi-step process that begins with spawn preparation, proceeds to substrate inoculation, spawn running, and results in mushroom fructification. The fruiting bodies are cultivated as edible mushrooms. Solid-state fermentation, an essential component of the mushroom-production process, allows the fungal mycelium to grow on a substrate. A variety of plant materials, especially agricultural waste products including sawdust, paddy straw, bagasse, cornstalks, used cotton, and banana stalks or leaves are used as common substrates for the cultivation of mushrooms. In Sri Lanka, *Pleurotus ostreatus* is commonly cultivated using rubber sawdust media [4-6].

Pleurotus ostreatus contains substantial amounts of carbohydrates, phenolic compounds, vitamins, minerals, and protein. They are abundant in both non-essential and essential amino acids, such as ornithine and gamma-aminobutyric acid (GABA) [7]. Non-essential amino acid GABA functions as a neurotransmitter, and ornithine helps produce arginine. For humans to be able to grow, repair, and preserve the functionality of the cells in our bodies, these amino acids are necessary [7,8].

Jayakumar *et al* (2006) conducted a study where it was found that extracts from *Pleurotus ostreatus* reduced CCl_4-induced hepatotoxicity in rats which provide evidence to the beneficial antioxidant activity of *Pleurotus ostreatus* [9]. Additionally, *Pleurotus* species have a number of therapeutic uses mainly due to the presence of low molecular weight secondary metabolites, including terpenoids, lactones, alkaloids, sterols, and phenolic compounds, as well as high molecular weight metabolites including proteins, lectins, and lipids. In Japan, Korea, and China, extracts from *Pleurotus* spp. are reported to be used frequently as possible supplements in radiation and chemotherapy [10]. Furthermore, a study by Chowdhury *et al* (2015) revealed that certain medicinal mushrooms, including *Pleurotus ostreatus* isolates, could aid in cardiovascular health, cancer prevention, have antiviral effects, bacterial resistance, parasite control, inflammation reduction, and blood sugar regulation [11]. Higher basidiomycetous mushrooms are known to contain a wide variety of biologically active polysaccharides, the vast majority of which are beta-D-glucans, a type of dietary fiber that has been proven to treat disorders such as hyperglycemia [12].

Various factors impact the nutritional composition, growth, and production of mushrooms. Variations in strains, growing methods, harvesting stages, growth substrate composition, and climatic conditions (e.g. temperature and humidity) have been reported to have an effect on the growth and other biochemical parameters of mushrooms [13].

While rubber sawdust is a known substrate for cultivating oyster mushrooms in Sri Lanka, the variations in nutritional and biochemical properties over successive harvests have not been extensively studied. This presents a critical research gap in understanding the optimal harvesting practices for maximizing nutritional value. Hence, this study was designed to evaluate and compare the differences in nutrient content, antioxidant, and antimicrobial properties of *Pleurotus ostreatus* cultivated on rubber sawdust media for three consecutive harvest cycles. The results of this study can be utilized to educate mushroom cultivators on providing nutritious and healthy produce to the consumers and strategies to optimize growth, efficiency and cultivation practices.

II. METHODOLOGY

A. Preparation of Substrate Bags

The mushrooms were cultivated at the Mushroom Center of AiGrow (Private) Limited in Rajagiriya, Sri Lanka. The ingredients required for 111 substrate bags were measured according to the quantities given in Table I.

TABLE I. INGREDIENTS AND THE QUANTITES USED

Ingredient	Quantity for one substrate bag	Quantity for 111 bags
Rubber sawdust	360 g	40 kg
White rice bran	36 g	4 kg
Calcium Carbonate	7.2 g	800 g
Magnesium Sulfate	0.72 g	80 g
Soy flour	3.6 g	400 g

Then, the measured ingredients were mixed in a commercially available substrate mixer by adding adequate amount of water until the desired consistency was achieved. Next, the substrate bags were prepared and sterilized using conventional media boilers for 3 hours at 100°C.

B. Inoculation of Spawns

After boiling the substrate bags, they were let to cool down and a spoonful of rice seeds containing *Pleurotus ostreatus* spawns were inoculated into each bag.

C. Incubation of Substrate Bags

The inoculated substrate bags were incubated at 26°C until the mycelium growth was completed (Fig. 2). Afterward, they were moved to the harvest room, the bags were opened and watered twice daily.

Fig. 2. Mycelium growth progress

D. Harvesting and Drying of the Mushrooms

Harvesting periods between the harvests were recorded. Three consecutive harvests were collected from five bags (R1, R2, R3, R4, R5) which were selected randomly, and fresh weights were recorded. The harvests were dried in a hot air oven at 40°C for 48 hours until around 90% moisture reduction was achieved. After drying, all harvests were crushed into a fine powder, and their dry weights were recorded. The parameters of the second and third harvests were compared with the parameters of the first harvest which was considered as the control.

E. Preparation of Aqueous Mushroom Extracts

4 g of the dried powdered mushroom samples were dissolved in 40 mL of distilled water in falcon tubes. The solutions were placed on a roller mixer for 48 hours and the extracts were filtered using Whatman no.1 filter paper and muslin cloth.

F. Water Holding Capacity (WHC) of Initial Substrate and Post-harvest Substrate

40 g of substrate was mixed with 80 mL of distilled water and left in the dark for 24 hours. The substrate was then filtered, and the eluted water volume was recorded. This procedure was repeated for the post-harvest substrate [14]. The WHC was calculated using the equation below.

WHC (%) = [(Volume of water added – Volume of water eluted) / Volume of water added] x 100

G. Biological Efficiency (BE) of Harvests

BE was calculated by the equation below for each substrate bag [14].

BE% = (Weight of fresh harvest / Weight of dry substrate) x 100

H. Total Carbohydrate Content Analysis Using Phenol-sulphuric Assay

A standard series of dextrose was prepared in concentrations between 200 µg/mL-1000 µg/mL. To 0.5 mL of each extract (20x diluted), distilled water (blank) and standard solution, 2.5 mL of 96% sulphuric acid and 5% phenol was added and incubated for 10 mins at 27°C.The absorbance was measured at 470 nm using a UV-vis spectrophotometer. A standard curve was plotted using the absorbances of the standard series and the unknown concentrations were calculated from the chart equation [16].

I. Total Protein Content Analysis Using Lowry Assay

A standard series of bovine serum albumin was prepared in concentrations between 200 µg/mL-1000 µg/mL. To 1 mL of each extract (20x diluted), distilled water (blank) and standard solution, 5 mL of Lowry A+B mix was added and incubated at Room Temperature (RT) for 10 mins. Then, Lowry C was added and incubated in the dark for 30 mins. The absorbance was measured at 660nm using a UV-vis spectrophotometer. A standard curve was plotted using the absorbances of the standard series and the unknown concentrations were calculated from the chart equation [17].

J. Qualitative Analysis of Bioactive Compounds

Protocols of the qualitative tests used to determine the presence of bioactive compounds are given in Table II.

TABLE II. QUALITATIVE TEST METHODS FOR BIOACTIVE COMPOUNDS

Compound	Test	References
Tannins	1 mL of 5% ferric chloride was added to 0.25 mL of extract.	[18]
Terpenoids	1 mL of chloroform and 1mL of conc. sulphuric acid was added to 0.25 mL of extract.	[19]
Polyphenols	Few drops of diluted iodine solution were added to 0.5 mL of extract.	[19]
Flavonoids	1 mL of 2% sodium hydroxide and 2 drops of dil. Hydrochloric acid was added to 1mL of extract.	[18]
Steroids	0.25 mL of chloroform and a drop of conc. sulphuric acid was added to 0.25 mL of extract.	[18]
Phytosterols	0.5 mL of chloroform and 1mL of conc. sulphuric acid was added to 0.5mL of extract.	[19]
Anthraquinones	1 mL of 10% ammonia solution was added to 0.25 mL of extract.	[18]

K. Total Phenolic Content Analysis Using Folin-Ciocalteu Assay

A standard series of gallic acid was prepared in concentrations between 200 µg/mL-1000 µg/mL. To 0.3 mL of each extract (20x diluted), distilled water (blank) and standard solution,1.5 mL of 7.5% sodium carbonate and 1.2mL of Folin-Ciocalteu reagent was added and incubated in the dark at RT for 1 hour. The absorbance was measured at 765nm using a UV-vis spectrophotometer. A standard curve was plotted using the absorbances of the standard series and the unknown concentrations were calculated from the chart equation [20].

L. Total Flavonoid Content Analysis Using Aluminum Chloride Colorimetric Assay

A standard series of quercetin was prepared in concentrations between 50 µg/mL-200 µg/mL. To 0.2 mL of each extract (20x diluted), distilled water (blank) and standard solution,1mL of Distilled water and 5% sodium nitrate was added and left at RT for 6 mins. 0.3mL of 10% aluminum chloride was added and left at RT for 5 mins. Finally, 0.4 mL of 1M of sodium hydroxide was added. The absorbance was measured at 510nm using a UV-vis spectrophotometer. A standard curve was plotted using the absorbances of the standard series and the unknown concentrations were calculated from the chart equation [21].

M. Analysis of Total Antioxidant Capacity Using Phosphomolybdenum Assay

A standard series of ascorbic acid was prepared at concentrations ranging from 200 µg/mL to 1000 µg/mL. To 0.1 mL of each extract (20x diluted), distilled water (blank), and standard solution, 1 mL of a reagent mix (0.6M H_2SO_4, 4mM ammonium molybdate, and 28mM sodium phosphate monobasic) was added, followed by incubation at 95°C for 90 minutes. After cooling, absorbance was measured at 695 nm using a UV-vis spectrophotometer. A standard curve was then plotted based on the absorbances of the standard series and the unknown concentrations were calculated from the chart equation [22].

N. 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging activity analysis

0.004% of DPPH was prepared using methanol. 1mL of prepared DPPH solution was added to 0.5 mL of extract (20x diluted) and incubated in the dark at RT for 30 mins. The absorbance was measured at 517 nm using a UV-vis spectrophotometer. The percentage of inhibition was calculated using the formula below [23].

$$\text{Inhibition ratio (\%)} = [(A_C - A_S)/A_C] \times 100$$

(A_C = the absorbance of the control, A_S = the absorbance of the sample)

O. Antibacterial Sensitivity Test Using Disk Diffusion Method

The bacterial suspension of *E. coli* and *S. aureus* was prepared and compared against 0.5 M of McFarland solution's turbidity. Then, 0.1 mL of bacterial suspension was spread evenly on the prepared Mueller-Hinton agar plates. Four discs were placed; Gentamicin as the positive control, Distilled water as the negative control, remaining two discs of the mushroom extract. The plates were incubated at 37°C for 24 hours. Sensitivity to antibiotics or mushroom extracts was determined via the measurement of zones of inhibition around each disc in mm [24].

P. Statistical Analysis

All the values are expressed as Mean ± Standard Error. Using Microsoft Excel 2019, the standard errors of the mean values were computed. With IBM SPSS software Version 29, a one-way ANOVA and a post-hoc Tukey test for multiple comparison analysis were performed. A *p*-value less than 0.05 was considered as significant.

III. RESULTS

A. Pleurotus ostreatus mushroom harvests

Table III indicates the images of first, second and third mushroom harvests.

TABLE III. MUSHROOMS FROM HARVESTS 1, 2 AND 3

Substrate Bag	1st harvest	2nd harvest	3rd harvest
R1			
R2			
R3			
R4			
R5			

Key: H1 = Harvest 1, H2 = Harvest 2 and H3 = Harvest 3

B. Total Harvesting Period

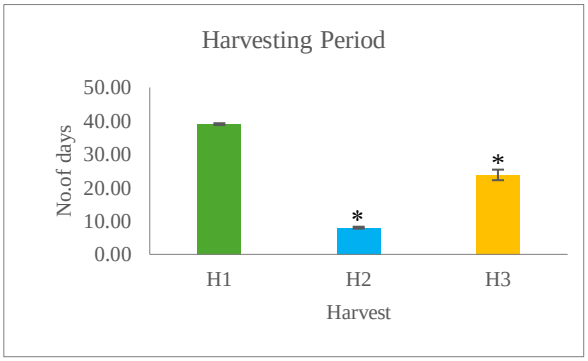


Fig. 3. *The average no of days taken from harvest to harvest, * represents p<0.05 compared to H1.*

The total harvesting period displays the number of days taken for each harvest. When the period reduces, the harvest can be taken sooner. The number of days taken for H1 since spawning the bags was significantly high compared to the number of days that were taken for H2 and H3 (Fig. 3).

C. Mushroom Yield

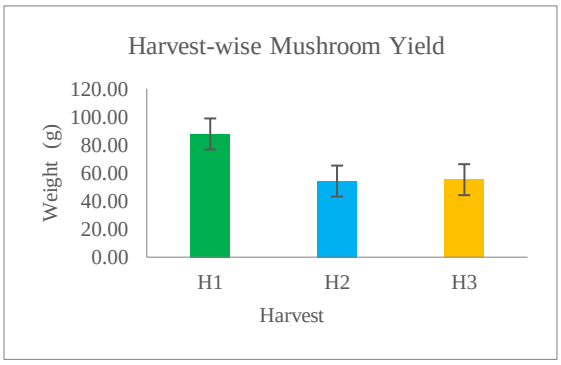


Fig. 4. *The average yield comparison between harvests*

The highest yield was present in H1, and the lowest yield was present in H2 (Fig. 4). There was no significant difference observed between the harvests.

D. Biological Efficiency (BE)

Table V indicates the BE values of the five substrate bags.

TABLE IV. THE BIOLOGICAL EFFICIENCY OF THE MUSHROOMS

Substrate bag	Biological efficiency
R1	25.01%
R2	11.52%
R3	11.78%
R4	18.70%
R5	17.16%

BE measures how effectively the mushroom substrate is converted into mushroom fruiting bodies. As shown in Table IV, R4 bag had the highest BE and the average BE of all 5 substrate bags was 16.8%.

E. Results of Qualitative Analysis of Bioactive compounds

According to Table V, polyphenols, steroids, flavonoids, phytosterols and terpenoids were present in the mushroom extracts while tannins and anthraquinones were absent.

TABLE V. RESULTS OF QUALITATIVE ANALYSIS OF BIOACTIVE COMPOUNDS

	R1	R2	R3	R4	R5
Tannins	Ab	Ab	Ab	Ab	Ab
Anthraquinone	Ab	Ab	Ab	Ab	Ab
Polyphenols	P	P	P	P	P
Steroids	P	P	P	P	P
Flavonoids	P	P	P	P	P
Phytosterols	P	P	P	P	P
Terpenoids	P	P	P	P	P

P: Present, Ab: Absent

F. Total Carbohydrate Content Analysis

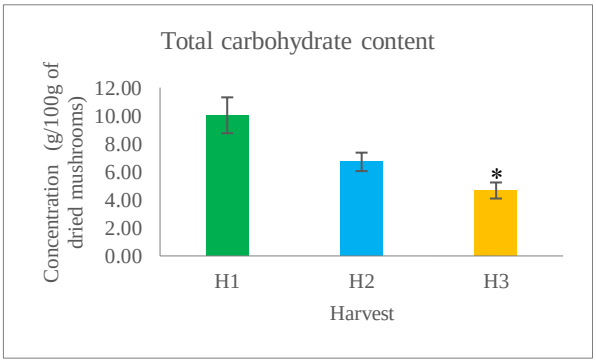


Fig. 5. *Total carbohydrate content comparison between harvests, * represents p<0.05 compared to H1.*

H1 recorded a significantly high carbohydrate content compared to H2 and H3. Lowest carbohydrate content was recorded in H3 (Fig. 5).

G. Total Protein Content Analysis

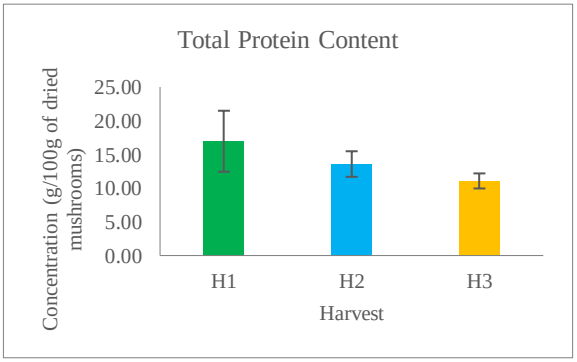


Fig. 6. *Total protein content comparison between harvests*

H1 had the highest protein content compared to H2 and H3, while H3 had the lowest total protein content (Fig. 6). There was no significant difference observed between the harvests.

H. Total Phenolic Content Analysis

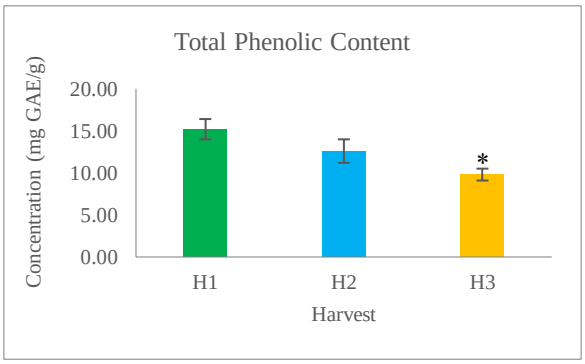


Fig. 7. *Total phenolic content comparison between harvests, * represents p<0.05 compared to H1.*

H1 had a significantly higher total phenolic content than H3, which recorded the lowest total phenolic content (Fig. 7).

I. Total Flavonoid Content Analysis

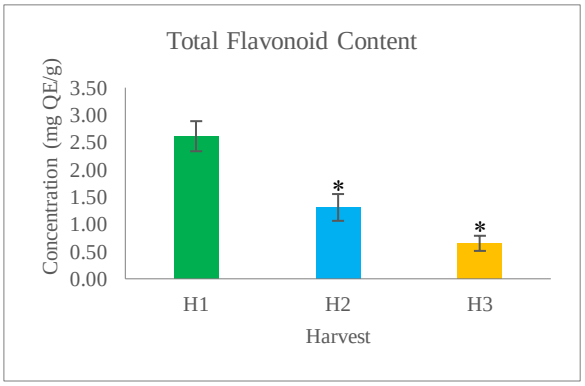


Fig. 8. *The total flavonoid content comparison between harvests, * represents p<0.05 compared to H1.*

H1 had a significantly high total flavonoid content compared to H2 and H3. The lowest total flavonoid content was recorded in H3 (Fig. 8).

J. Analysis of DPPH radical scavenging activity

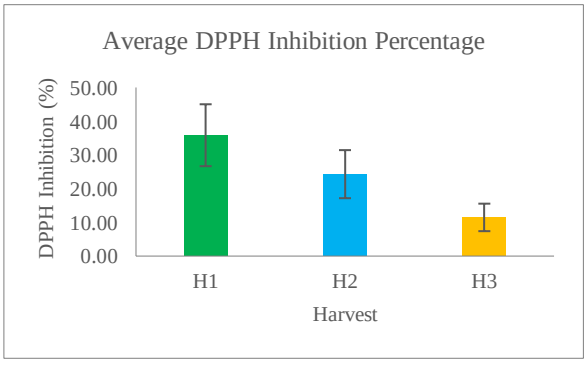


Fig. 9. *DPPH radical scavenging comparison between harvests*

H1 had the highest inhibition percentage whereas H3 had the lowest inhibition percentage (Fig. 9). However, there were no significant differences between the harvests.

K. Total Antioxidant Capacity Analysis

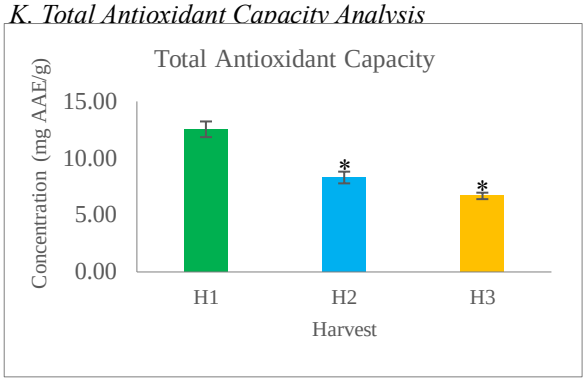


Fig. 10. *The total antioxidant capacity comparison between harvests, * represents p<0.05 compared to H1.*

H1 had a significantly higher antioxidant capacity compared to H2 and H3, which recorded the lowest antioxidant capacity (Fig. 10).

L. Water Holding Capacity of the Substrates

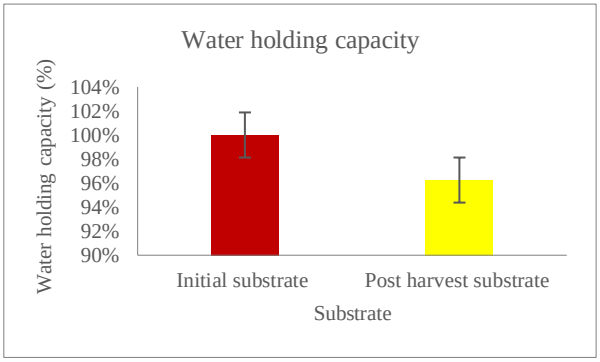


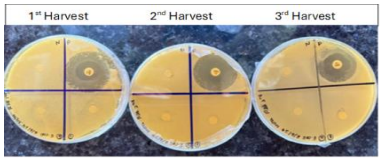
Fig. 11. *Water holding capacity comparison between initial substrate and post-harvest substrate.*

No water was eluted from the initial substrate thus had a 100% WHC and the post-harvest substrate had 3 mL of water eluted, thus had a 96.25% WHC (Fig. 11).

M. Antibacterial Sensitivity Test Results

Pleurotus ostreatus does not possess antimicrobial properties as no zones of inhibition were observed against either of the bacterial strains, *E. coli* (Table VI) and *S. aureus* (Table VII).

TABLE VI. ANTIBACTERIAL SENSITIVITY TEST RESULTS OF *Pleurotus ostreatus* AGAINST *E. coli* STRAIN

Substrate Bag	***Plates with Zones of Inhibition***
R1	

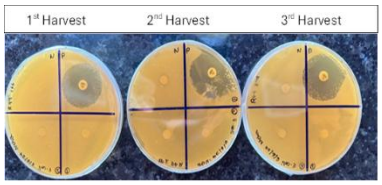
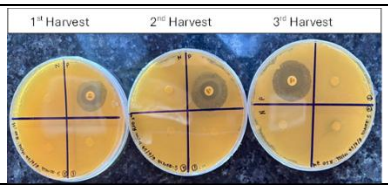
R4	

TABLE VII. ANTIBACTERIAL SENSITIVITY TEST RESULTS OF *Pleurotus ostreatus* AGAINST *S. aurues* STRAIN

Substrate Bag	***Plates with Zones of Inhibition***
R1	
R4	

IV. DISCUSSION

This study focuses on the mushroom species *Pleurotus ostreatus* grown on rubber sawdust media and its harvest-wise differences in nutrient content, antioxidant properties, and antimicrobial activity. The main goal of this study was to determine how the characteristics change with each harvest, providing knowledge that will help optimize the cultivation of mushrooms and improve their nutritional profile.

The period taken for the *Pleurotus ostreatus* till its 1st harvest was 39 days, which falls within the range of 27 to 40.67 days as reported by Girmay *et al*., in 2016, indicating that the duration from spawn seeding to harvesting depends on the substrate used, growing conditions and physiological requirements, such as consistent humidity and temperature [25].

The biological efficiency of the substrate was impacted by the variations in yield. Typically, a higher yield from the substrate corresponds to a higher BE value. The average BE inclusive of all three harvests accounted to 16.8%, which is low compared to *Pleurotus ostreatus* grown on other substrates namely, cottonseed hulls and rice paddy straws. According to a study done by M. Obodai, L. C. B. Sawyerr and Johnson in 2000, the reason for this could be that lignocellulosic components of sawdust often have low protein contents, which is rather insufficient for cultivating mushrooms [26]. Thus, to release the necessary elements for the development of mushroom mycelia more effectively, the sawdust substrate used in mushroom production needs to be composted for a while to break down the cellulose and lignin components of the wood or be used in different proportions with other substrate components such as cottonseed and wheat straw. Additionally, potassium, phosphate, and nitrogen may also be used to increase the substrate efficiency [27-29].

The yield of the *Pleurotus ostreatus* was highest in the 1st harvest compared to the 2nd and 3rd harvests. According to a study done by Argaw *et al*, in 2023, *Pleurotus ostreatus* has produced a similar yield when grown on sawdust media, when compared to other substrate media such as cottonseed but comparatively low yield in substrates like bagasse. Therefore, this explains the nutrients present in the substrate contribute to the yield of *Pleurotus ostreatus* [30].

The WHC of the initial substrate was 100%, which means that the substrate was able to retain the maximum amount of moisture possible. This aids in the growth of *Pleurotus ostreatus* as it requires optimal levels of moisture. However, the post-harvest substrate after 3 harvests, had reduced to 96.25% of WHC. The post-harvest substrate can further be used in either proportions or as a whole to grow Greenhouse or field crops or even be used as soil fertilizers [31].

Bioactive components are active substances that are found in trace amounts in mushrooms and have the power to either prevent or treat existing medical conditions. Nitrogen-containing substances, including bioactive phytosterols and flavonoids, can regulate a number of metabolic processes in the human body, including the scavenging of free radicals, the stimulation or inhibition of gene expression, receptor activity, and enzyme activity. The presence of terpenoids, flavonoids, polyphenols, phytosterols, and steroids was confirmed by qualitative assays [32].

As the mycelium ages or when the harvest cycle progresses, there is a noticeable nutritional depletion that happens, which influences their synthesis. This was evident by the quantitative analysis conducted on the mushrooms of such nutrients [33].

The total carbohydrate analysis revealed that the amount of carbohydrate present was the highest in the first harvest with an average of 10g/100g of the mushrooms and reduced with a significant amount in second and third harvests. In a study conducted by Debu Kumar Bhattacharjya *et al*., in 2015, *Pleurotus ostreatus* was grown on different sawdust substrates which included different trees such as fig, mahogany, and eucalyptus. Different sawdust combinations resulted in different percentages ranging from 39.67% - 42.36% of carbohydrates being present in their harvest. Thus, it is evident that the substrate content and type of sawdust also play a role in the nutrient composition of the *Pleurotus ostreatus* [34].

The average protein content in the first harvest was 16.95g/100g of mushrooms and it reduced with second and third harvests. This supports previous

research findings that shows *Pleurotus* spp contain a higher protein content than other nutrient compounds while it contributes to 30% of the dry weight as they are abundant in various types of amino acids such as tryptophan and leucine. The type of substrate and nitrogen availability also has a direct influence on the protein concentration because the fungi break down the organic material in the substrate into simpler molecules like protein, which are then absorbed into the growth of the fruiting body. As more harvests grow, the substrate becomes exhausted resulting in depletion of nutrients [35-37].

The results of the DPPH assay interpret that the inhibition ratio is the highest in the first harvest and reduced with the second and third harvests. In line with these results, total antioxidant capacity assay results also demonstrated the highest antioxidant capacity in the first harvest compared to the other two harvests. Every harvest modifies the substrate's composition, which impacts the availability of precursors required for the synthesis of antioxidants, thus the gradual reduction. In a study conducted by González-Palma *et al.*, in 2016, it was evident that in comparison to other edible mushroom species such as *Agaricus bisporus* and *Boletus edulis, Pleurotus ostreatus* had the lowest amount of antioxidants present (78.43, 58.06 and 38.31 mg AAE/mL respectively), which aligns with the low range of scavenging activity in the DPPH assay and the concentration equivalence to ascorbic acid for the phosphomolybdenum assay in this study [38,39].

The constituents such as rice bran that was present in the substrate, supplement the necessary precursors for the biosynthesis of phenolic compounds, enhancing their content in the mushrooms. The average phenolic content in the first harvest was 15.18mg/g of gallic acid equivalents and reduced with the second and third harvests. This is in line with the evidence from a study done by Gąsecka *et al.,* in 2015 where the comparison was done between *Pleurotus ostreatus* and *Pleaurotus eryngii* grown on sawdust enriched with selenium salts in which the average phenolic content of *Pleurotus ostreatus* was between ~2 to >30mg/g [40,41].

The amount of flavonoid content in *Pleurotus ostreatus* is considerably low. This could possibly be due to the biosynthesis pathway for the production of flavonoids is not as efficient in fungi as it is in plants. The average of total flavonoid content was 2.61 mg/g of QE for the first harvest and it was reduced with the second and third harvests, which is in line with the previously reported flavonoid values of 0.025-3.131 mg QE/g for the *Pleurotus ostreatus* species [42,43].

In the antibiotic sensitivity test against *E. coli* and *S. aureus* bacteria, *Pleurotus ostreatus* did not display antibacterial effects as depicted by the absence of a zone of inhibition against the mushroom extracts. However, a study conducted by Sinethemba *et al*., in 2023, supports the evidence of *Pleurotus ostreatus* having antibacterial properties. Factors such as solvent extraction of samples could be a possible reason for this difference and further investigations with a broader set of conditions may help in clarifying the antibacterial properties of the mushrooms [44].

V. CONCLUSION

This study found significant differences in the harvest-wise total carbohydrate content, antioxidant capacity, phenolic, and flavonoid content of *Pleurotus ostreatus* mushrooms, with the first harvest offering the highest nutritional and bioactive value. Successive harvests showed a decline in nutrient availability, affecting the mushrooms' nutritional quality. To improve the nutrient and antioxidant content in later harvests, adding nutrients like carbon and nitrogen or using a nutrient-rich substrate can be recommended.

VI. REFERENCES

[1] G. Ogundele, S. Salawu, I. Abdulraheem, and O. Bamidele, "Nutritional Composition of Oyster Mushroom (*Pleurotus ostreatus*) Grown on Softwood (*Daniella oliveri*) Sawdust and Hardwood (*Anogeissus leiocarpus*) Sawdust," British Journal of Applied Science & Technology, vol. 20, pp. 1–7, Jan. 2017.

[2] F. Ahmad Zakil *et al.*, "Growth performance and mineral analysis of *Pleurotus ostreatus* from various agricultural wastes mixed with rubber tree sawdust in Malaysia," Bioresource Technology Reports, vol. 17, Feb. 2022.

[3] R. Muslimin *et al.*, "The effect of different substrates on oyster mushroom (*Pleurotus ostreatus*) spawn growth," IOP Conference Series: Earth and Environmental Science, vol. 911, Nov. 2021.

[4] M. Hultberg, H. Asp, K. J. Bergstrand, and O. Golovko, "Production of oyster mushroom (Pleurotus ostreatus) on sawdust supplemented with anaerobic digestate," Waste Management, vol. 155, pp. 1–7, Jan. 2023.

[5] Nafissa, Fathie Ahmad Zakil, W. Nur, N. Ali, and O. Hassan, "The usage of empty fruit bunch (EFB) and palm pressed fibre (PPF) as substrates for the cultivation of *Pleurotus ostreatus*," Dec. 2008.

[6] Mohideen, O. Perera, and G. Liyanage, "Effects of Rubber Sawdust and Paper waste as Substrates for Cultivating American Oyster Mushrooms (*Pleurotus ostreatus*): Their Influence on Nutrient Composition, Bioactive Compound Levels and Antioxidant Capacity," Journal of Applied Learning, vol. 1, pp. 1–2023, Jul. 2023.

[7] L. R. Dávila, Walter Murillo A, Cristian, Héctor Suárez M, and Jonh J. Méndez A, "Evaluation of nutritional values of wild mushrooms and spent substrate of *Lentinus crinitus* (L.) Fr," Heliyon, vol. 6, pp. e03502–e03502, Mar. 2020.

[8] G. Ogundele, S. Salawu, I. Abdulraheem, and O. Bamidele, "Nutritional Composition of Oyster Mushroom (*Pleurotus ostreatus*) Grown on Softwood (*Daniella oliveri*) Sawdust and Hardwood (*Anogeissus leiocarpus*) Sawdust," *British Journal of Applied Science & Technology*, vol. 20, pp. 1–7, Jan. 2017.

[9] T. Jayakumar, E. Ramesh, and P. Geraldine, "Antioxidant activity of the oyster mushroom, *Pleurotus ostreatus*, on CCl4-induced liver injury in rats," Food and Chemical Toxicology, vol. 44, pp. 1989–1996, Dec. 2006.

[10] B. Jakopovic *et al.*, "Treatment with Medicinal Mushroom Extract Mixture Inhibits Translation and Reprograms Metabolism in Advanced Colorectal Cancer Animal Model as Evidenced by Tandem Mass Tags Proteomics Analysis," Frontiers in Pharmacology, vol. 11, p. 1202, 2020.

[11] M. Chowdhury, K. Kubra, and S. Ahmed, "Screening of antimicrobial, antioxidant properties and bioactive compounds of some edible mushrooms cultivated in Bangladesh," Annals of Clinical Microbiology and Antimicrobials, vol. 14, no. 1, 2015.

[12] K. Arunachalam, P. S. Sreeja, and X. Yang, "The Antioxidant Properties of Mushroom Polysaccharides can Potentially Mitigate Oxidative Stress, Beta-Cell Dysfunction and Insulin Resistance," Frontiers in Pharmacology, vol. 13, May 2022.

[13] G. Ogundele, S. Salawu, I. Abdulraheem, and O. Bamidele, "Nutritional Composition of Oyster Mushroom (*Pleurotus ostreatus*) Grown on Softwood (*Daniella oliveri*) Sawdust and Hardwood (*Anogeissus leiocarpus*) Sawdust," *British Journal of Applied Science & Technology*, vol. 20, pp. 1–7, Jan. 2017.

[14] C. Muswati, K. Simango, L. Tapfumaneyi, M. Mutetwa, and W. Ngezimana, "The Effects of Different Substrate Combinations on Growth and Yield of Oyster Mushroom (*Pleurotus ostreatus*)," International Journal of Agronomy, vol. 2021, pp. 1–10, May 2021.

[15] B. Argaw, T. Tesfay, T. Godifey, and N. Asres, "Growth and Yield Performance of Oyster Mushroom (*P. ostreatus*) Using Waste Leaves and Sawdust," International Journal of Agronomy, vol. 2023, Oct. 2023.

[16] Michel. DuBois, K. A. Gilles, J. K. Hamilton, P. A. Rebers, and Fred. Smith, "Colorimetric Method for Determination of Sugars and Related Substances," Analytical Chemistry, vol. 28, pp. 350–356, Mar. 1956.

[17] H. K. Mæhre, L. Dalheim, G. K. Edvinsen, E. O. Elvevoll, and I.-J. Jensen, "Protein Determination—Method Matters," Foods, vol. 7, p. 5, Jan. 2018.

[18] C. N. W. Sitati, K. O. Ogila, R. W. Waihenya, and L. A. Ochola, "Phytochemical Profile and Antimicrobial Activities of Edible Mushroom *Termitomyces striatus*," Evidence-based Complementary and Alternative Medicine : eCAM, vol. 2021, Oct. 2021.

[19] A. Porselvi and R. Vijayakumar, "Evaluation of paddy straw varieties for the nutritional composition of oyster mushroom (*Pleurotus florida* and *Pleurotus eous*)," Agricultural Research Journal, vol. 57, p. 564, 2020.

[20] N. Siddiqui, A. Rauf, A. Latif, and Z. Mahmood, "Spectrophotometric determination of the total phenolic content, spectral and fluorescence study of the herbal Unani drug Gul-e-Zoofa (*Nepeta bracteata Benth*)," Journal of Taibah University Medical Sciences, vol. 12, pp. 360–363, Aug. 2017.

[21] A.O. Ikhane, Sithole, Siphesihle Z, Cele, Nkosinathi D, Osunsanmi, Foluso O, R. A. Mosa, and A. R. Opoku, "In Vitro Antioxidant and In Silico Evaluation of the Anti-β-Lactamase Potential of the Extracts of *Cylindrospermum alatosporum* NR125682 and *Loriellopsis cavenicola* NR117881," Antioxidants, vol. 13, p. 608, May 2024.

[22] S. Cao, C. Wan, Y. Yu, S. Zhou, W. Liu, and S. Tian, "Antioxidant activity and free radical-scavenging capacity of *Gynura divaricata* leaf extracts at different temperatures," Pharmacognosy Magazine, vol. 7, p. 40, 2011.

[23] S. Baliyan *et al.*, "Determination of Antioxidants by DPPH Radical Scavenging Activity and Quantitative Phytochemical Analysis of Ficus religiosa," *Molecules*, vol. 27, p. 1326, Feb. 2022.

[24] M. Chowdhury, K. Kubra, and S. Ahmed, "Screening of antimicrobial, antioxidant properties and bioactive compounds of some edible mushrooms cultivated in Bangladesh," Annals of Clinical Microbiology and Antimicrobials, vol. 14, no. 1, p. 8, 2015.

[25] Z. Girmay, W. Gorems, G. Birhanu, and S. Zewdie, "Growth and yield performance of *Pleurotus ostreatus* on different substrates," AMB Express, vol. 6, Oct. 2016.

[26] M. Obodai, L. C. B. Sawyerr, and Johnson, "Yield of seven strains of oyster mushrooms (*Pleurotus spp*.) grown on composted sawdust of *Triplochiton scleroxylon*.," Tropical science, vol. 40, pp. 95–99, Jan. 2000.

[27] C. Muswati, K. Simango, L. Tapfumaneyi, M. Mutetwa, and W. Ngezimana, "The Effects of Different Substrate Combinations on Growth and Yield of Oyster Mushroom (*Pleurotus ostreatus*)," International Journal of Agronomy, vol. 2021, pp. 1–10, May 2021.

[28] M. Moonmoon, Md. N. Uddin, S. Ahmed, N. J. Shelly, and Md. A. Khan, "Cultivation of different strains of king oyster mushroom (*Pleurotus eryngii*) on saw dust and rice straw in Bangladesh," Saudi Journal of Biological Sciences, vol. 17, pp. 341–345, Oct. 2010.

[29] J. Liu *et al.*, "Effect of nitrogen, phosphorus and potassium fertilization management on soil properties and leaf traits and yield of *Sapindus mukorossi*," Frontiers in Plant Science, vol. 15, Mar. 2024.

[30] B. Argaw, T. Tesfay, T. Godifey, and N. Asres, "Growth and Yield Performance of Oyster Mushroom (*P. ostreatus* Using Waste Leaves and Sawdust," International Journal of Agronomy, vol. 2023, p. e8013491, Oct. 2023.

[31] D. L. Rinker, "Spent Mushroom Substrate Uses," Edible and Medicinal Mushrooms, pp. 427–454, Aug. 2017.

[32] V. Sorrenti, I. Burò, V. Consoli, and L. Vanella, "Recent Advances in Health Benefits of Bioactive Compounds from Food Wastes and By-Products: Biochemical Aspects," International Journal of Molecular Sciences, vol. 24, p. 2019, Jan. 2023.

[33] J. Wu *et al.*, "Calcium dynamics during the growth of *Agaricus bisporus*: implications for mushroom development and nutrition," Chemical and Biological Technologies in Agriculture, vol. 10, Sep. 2023.

[34] D. K. Bhattacharjya, R. K. Paul, M. N. Miah, and K. U. Ahmed, "Comparative Study on Nutritional Composition of Oyster Mushroom (*Pleurotus ostreatus*) Cultivated on Different Sawdust Substrates," vol. 1, pp. 93–98, Jan. 2015.

[35] L. Satpathy, "Quantitation of Total Protein Content in Some Common Edible Food Sources by Lowry Protein Assay," Letters in Applied NanoBioScience, vol. 9, pp. 1275–1283, Jul. 2020.

[36] M. B. Bellettini *et al.*, "Factors affecting mushroom *Pleurotus spp*.," Saudi Journal of Biological Sciences, vol. 26, no. 4, pp. 633–646, May 2019.

[37] C. Martín, G. I. Zervakis, S. Xiong, G. Koutrotsios, and K. O. Strætkvern, "Spent substrate from mushroom cultivation: exploitation potential toward various applications and value-added products," Bioengineered, vol. 14, no. 1, Sep. 2023.

[38] S. Baliyan *et al.*, "Determination of Antioxidants by DPPH Radical Scavenging Activity and Quantitative Phytochemical Analysis of *Ficus religiosa*," Molecules, vol. 27, p. 1326, Feb. 2022.

[39] I. González-Palma *et al.*, "Evaluation of the Antioxidant Activity of Aqueous and Methanol Extracts of *Pleurotus ostreatus* in Different Growth Stages," Frontiers in Microbiology, vol. 7, Jul. 2016.

[40] N. Kumar and N. Goel, "Phenolic acids: Natural versatile molecules with promising therapeutic applications," Biotechnology Reports, vol. 24, p. e00370, Dec. 2019.

[41] M. Gąsecka, M. Mleczek, M. Siwulski, and P. Niedzielski, "Phenolic composition and antioxidant properties of *Pleurotus ostreatus* and *Pleurotus eryngii* enriched with selenium and zinc," European Food Research and Technology, vol. 242, pp. 723–732, Nov. 2015.

[42] S. Egra, I. R. W. Kusuma, E. T. Arung, and H. Kuspradini, "The potential of white-oyster mushroom (*Pleurotus ostreatus*) as antimicrobial and natural antioxidant," Biofarmasi Journal *of Natural Product Biochemistry*, vol. 17, no. 1, Jul. 2019.

[43] J. Azieana, M. N. Zainon, A. Noriham, and M. N. Rohana, "Total Phenolic and Flavonoid Content and Antioxidant Activities of Ten Malaysian Wild Mushrooms," OALib, vol. 04, pp. 1–9, 2017.

[44] S. H. Yakobi, S. S. Mkhize, and O. J. Pooe, “Screening of Antimicrobial Properties and Bioactive Compounds of *Pleurotus Ostreatus* Extracts against *Staphylococcus Aureus*, *Escherichia coli*, and *Neisseria Gonorrhoeae*,” Biochemistry Research International, vol. 2023, pp. 1–9, Apr. 2023.

Investigate the Water Purification Properties of *Strychnos Potatorum* (Ingini) Seeds Powder, *Moringa Olifera* Seeds Powder and Activated Charcoal Powder

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***Abstract*— Water purification is essential for addressing drinking water challenges. This research aimed to find suitable Biosorbents for the purification of the water. Moringa (*Moringa Oleifera*), and Ingini (*Strychonos potatum)*, seeds were used and their efficiency was compared with Activated charcoal. Water Samples were collected from a Nuwara Wawa in Anuradhapura. The seeds were sun-dried for three days and then ground into powder. Different amounts of this seed powder (10ppm, 20ppm, 30ppm, 40ppm, 50ppm, 60ppm, 70ppm, 80ppm, 90ppm, 100ppm) were added to the water samples, stirred rapidly for 2 minutes, and gently mixed for 10 minutes to promote coagulation. After settling, the water samples were filtered using a 45-pore size filter paper and analyzed. The physical, chemical, and biological properties of the treated water samples were compared with Sri Lanka Standards (SLS) guidelines. (Standard Methods for the examination of water and Wastewater 1985 – Drinking water). Results indicated that water samples treated with *Strychnos potatorum* at 60 mg/L for 10 hours, *Moringa oleifera* at 80 mg/L for 2 hours, and activated charcoal at 100 mg/L for 2 hours yielded the most accurate purification, meeting the required SLS standards. These findings demonstrate the effectiveness of these natural biosorbents in improving water quality, with potential water purification system.**

Keywords*— Water purification, Potatorum (ingini) seeds, Moringa oleifera seedsn

I. INTRODUCTION

Drinking Water is a main requirement for human beings. Water is essential for metabolism, Cellular homeostasis, temperature regulation, substrate transport across membranes and circulatory function in the human body. The human body is approximately 75% water (Ketabchi 2023).

People in rural areas (Nochchiyagama, Nallachchiya, Eppawala,….etc.) have been experiencing issues with drinking water because of a lack of infrastructure and funding. Many rural populations utilise untreated water for drinking, and many of these regions are situated in inaccessible or difficult-to-reach places, making it challenging to bring purified water or clean water sources to these groups. People living in rural areas may occasionally lack the infrastructure required for the delivery and purification of water. Rural areas may find it difficult to pay the high costs and continuous resources involved in the construction and upkeep of water purification facilities and distribution networks. Rural areas may lack the funding necessary to install water filtration systems or to buy treated water from outside suppliers. Residents may be forced to depend on untreated water sources such as wells, rivers, or lakes, which may be tainted with chemicals, bacteria, or other contaminants (A Omarova, 2019). In addition, industrial waste, agricultural runoff, and other types of pollution can pollute rural water sources, rendering them unsafe to drink without adequate treatment. Sometimes people living in rural areas lack access to information regarding water sanitation and hygiene practices, or they may not be completely aware of the dangers of drinking untreated water.

Due to the release of improperly treated wastewater into the groundwater, untreated water includes bioorganisms and heavy metals such fluoride, chloride, nitrate, nitrite, sulphate, phosphate, and iron that may be harmful to human health. It is essential to remove impurities from polluted water before use. However, people living in rural villages often cannot afford modern water treatment methods, which rely on chemical coagulants. Moreover, these chemical coagulants have been linked to health risks, including the spread of diseases like cancer. (Ramavandi 2014), there were contaminants and pathogenic microorganisms in the surface water that might have an adverse effect on human health. Millions of people die each year from water-bone illnesses in many rural areas, namely as a result of surface water contamination and inadequate wastewater treatment (Grant et al., 2012). Cholera, diarrhoea, dysentery, hepatitis A, polio, and typhoid are among the illnesses that can spread due to contaminated water and inadequate sanitation.

The contaminated water can be cleaned using naturally occurring biosorbents, which are thought to be safe for the environment and not harmful to human health. Compared to synthetic adsorbents or chemical treatments, biosorbents are environmentally sustainable since they are usually renewable and biodegradable. (S. Kainth · 2024) Comparing the cost of water filtration to traditional methods, biosorbents can be more affordable because many of them are easily accessible as waste products from the forestry, food processing, and agricultural sectors. When compared to traditional water treatment techniques, biosorption procedures frequently require less energy

input, which makes them more economical and energy-efficient. Local sources of biosorbents are available, which is especially advantageous for remote areas where access to costly filtration equipment or traditional water treatment technologies may be restricted (Ketabchi 2023). The biosorbents don't cause harm and are safe. Biosorbents are generally non-toxic and present little damage to the environment or public health, in contrast to certain chemical treatments. They can therefore be used in applications for treating drinking water.

Moringa seeds, with their ability to clot and bind with bacteria and pollutants, are used in water purification. They prevent the formation of harmful microorganisms and are easily grown in tropical and subtropical regions. These seeds are affordable, practical, and environmentally friendly, making them an ideal choice for rural areas with limited resources (Jon Greaves 2022).

Strychnos potatorum seeds contain organic coagulants that attach to bacteria and pollutants, aiding in water purification. They also have antibacterial properties, preventing germ formation and requiring no artificial chemicals or energy-intensive procedures, making them an environmentally friendly method.

Activated charcoal is a useful water filtration tool due to its adsorption properties. It traps contaminants like pesticides, chlorine, organic molecules, and volatile organic compounds, effectively extracting them from water. This process improves water taste and smell and removes dangerous materials. Although less efficient at eliminating heavy metals, dissolved salts, or microbiological contaminants, activated charcoal remains a popular choice for water purification.

The research gap could be in comparative studies involving Ingini seeds powder algongside Moringa and charcoal, especially of Ingini seeds are less researches. (S.Arasaretnam.2018). Investigating whether a combination of these powders could have synergistic effects in water purification could be an unexplored area. (Zakaria et al.2018). Evaluating these materials effectiveness water sources could reveal gaps in existing research.

Natural water treatment methods often have minimal environmental impact compared to conventional chemical treatments. They can help maintain the ecological balance of aquatic ecosystems by avoiding the introduction of harmful chemicals (R.K.Mishra 2023).

Because they often need less energy and resources to execute and maintain, natural therapy approaches can prove to be more cost-effective over time. Its reliance on freely available natural materials and methods eliminates the need for costly chemicals and infrastructure. The water produced by natural treatment techniques is often safer and healthier to drink. As a result, the treated water keeps its original characteristics and vital minerals without the use of potentially dangerous chemicals. Local communities can be involved in the management and conservation of water resources by implementing natural ways of treating water.(S.Tharanigaivel 2023)

Compared to conventional treatments, natural treatment systems may be more resistant to the effects of climate change. They frequently adjust to environmental changes more skillfully, offering dependable water treatment even in the face of erratic weather. Certain natural treatment techniques, such as creating wetlands, offer a range of plant and animal species support and habitat. They purify water and support the preservation of biodiversity at the same time. Natural treatment methods can improve the surrounding landscapes' and water treatment facilities' aesthetic appeal. They can be included in public areas like parks, gardens, and other places where people congregate to enjoy leisure and education. (N.H.Pakharuddin 2021)

II. Materials and Methods

A. Description of the study sites

The study was conducted on the raw water from Nuwara Wewa in Anuradhapura, Sri Lanka. The analysis was carried out at the National Water Supply and Drainage Board Regional Laboratory in Anuradhapura, from December 2023 to April 2024

The primary water filtration materials utilized in this investigation were activated charcoal, *strychonos potatum* (Ingini) seeds, and *Moringa oleifera* seeds. Samples of raw water were gathered from Nuwara Wawa. The *Moringa oleifera* tree in the Anuradhapura region was used to gather *Moringa oleifera* seeds. From the *strychonos potatum* tree in the Anuradhapura region, seeds were gathered. The burned coconut shells were used to gather activated charcoal. In an oxygen-starved environment, these burned coconut shells created by employing coconut shells must be exposed to a range of high temperatures between 300 and 500 degrees Celsius. For a number of hours to decompose into charcoal. The pH meter measures the pH. The TN 500 Turbidity meter measures turbidity. The EC meter measures the EC. The chemical parameters were tested by the HACH DR6000 Spectrometer.

B. Treatment plan analysis

01. Collect seeds and dry them for 3 days in sunlight, then grind and sieve them to obtain a fine powder.

02. Take 1 liter of raw water sample from Nuwara Wewa and add varying amounts of the seed powders from all three materials (10ppm, 20ppm, 30ppm, 40ppm, 50ppm, 60ppm, 70ppm, 80ppm, 90ppm, 100ppm)test the 10ml of Water.

03. Stir the samples rapidly for two minutes, followed by 10 minutes of gentle mixing to promote coagulation (M. and chonde,M 2012).

04 Allow the samples to settle for different residence times (30min, 1hr, 2hr, 4hr, 6hr, 10hr, 12hr)

05. Filter the sample using 45µm pore size filter paper

06. Conduct tests on the filtered samples

Electrical conductivity (EC), turbidity, and pH were the primary criteria examined to determine the appropriateness of the water samples. If the turbidity is less than 2 NTU, the EC is less than 500 µS/cm, and the pH is between 6.5 and 8.5, the water sample is deemed appropriate. Samples that did not fit these requirements were thrown away, and those that did were chosen for additional research.

(NTU)-Turbidity measuring unit - This study Investigate the Water purification properties (color, Turbidity,T.D.S, pH, Chloride, Alkalinity, Hardness,Nitrate, Nitrite, Sulfate, Fluoride, Phosphate, Iron, Ec, E.coli, Coliform) of Ingini seeds Powder, *moringa oleifera* seeds Powder and charcoal powder. The main objective here is to investigate how purification properties vary with SLS level. This research is an analysis of the purification properties with time (with Ingini seeds powder, *Moringa Oleifera*, charcoal powder) The specific objective here is to investigate how purification properties vary with time and analysis of the purification properties with concentration (with Ingini seeds powder, *Moringa Oleifera*, charcoal powder)another one is how purification properties vary with concentration.

III. Result and Discussion

Table I illustrates the optimal concentrations (ppm) and residence times for effective water purification using Ingini, Moringa, and activated charcoal. The results show that all three materials achieved desirable pH, turbidity, and electrical conductivity (EC) values, with each meeting the Sri Lanka Standards (SLS) for drinking water quality. It indicated that water samples treated with *Strychnos potatorum* at 60 mg/L for 10 hours, *Moringa oleifera* at 80 mg/L for 2 hours, and activated charcoal at 100 mg/L for 2 hours yielded the most accurate purification.

TABLE I. Overall parameter change

Overall parameters change					
Parameters	Untreated	Egini seeds (60pp) S.dv	M.olifera seeds (80ppm) S.dv	Activated charcoal (100ppm) S.dv	Standard value
Color	29	20	17	18	15
Turbidity (NTU)	3.06	1.89	1.86	1.97	2
T.D.S (mg/L)	289	262	254	241	500
pH	7.64	6.82	6.63	7.34	6.5-8.5
Chloride (mg/L)	63	35.2	33.4	40.3	250
Alkalinity (mg/L)	151	124	116	103	200
Hardness (mg/L)	157	148	145	141	250
Nitrate (mg/L)	1.32	1.26	1.24	1.25	50
Nitrite (mg/L)	0.003	0.002	0.001	0.0015	3.0
Sulfate (mg/L)	2	1.8	1.6	1.7	250
Fluoride (mg/L)	0.36	0.28	0.3	0.31	1.0
Phosphate (mg/L)	0.05	0.043	0.038	0.039	2.0
Iron (mg/L)	0.02	0.017	0.016	0.014	0.3
EC (µS/cm)	451	424	416	403	-
E.coli (nos/100ml)	>2000	3	2	5	0
Coliform (nos/100ml)	>2000	20	15	23	3

TABLE II. Selected parameter change

	Selected ppm	Selected time (h)	pH	Turbidity (NTU)	EC (µS/cm)
Ingini	60	10	6.82	1.89	424
Moringa	80	2	6.63	1.86	416
Active.C	100	2	7.34	1.97	403

pH

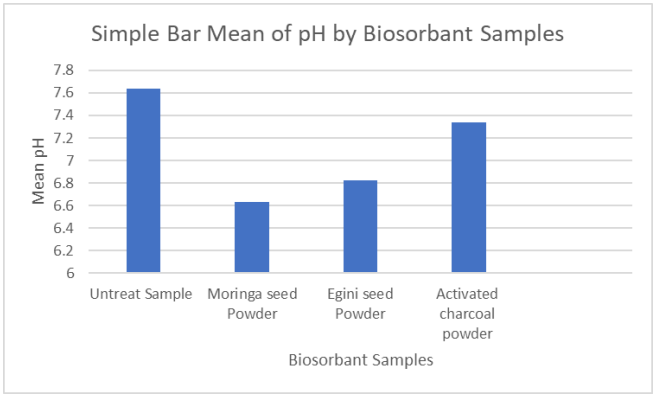

Fig. 1. Mean of pH change

The values of the mean pH are shown in the graph. S. potatorum contains a variety of substances, including protein molecules, agglutinin molecules, broccolini lectin proteins, alkaloid strychnine, and alkaloid brucine. These substances reduce the pH of water. (environmental-technology-and-innovation November 2021, 101983).

Water-soluble cationic proteins with a net positive charge make up the active proteins of coagulants in the Moringa seeds (Nadabigengesere et al. 1995). The positive charge of Moringa seeds neutralizes the negative charge of colloids in water. Chemical functional groups like hydroxyl groups (-OH) and carboxyl groups (-COOH) can also be present on the surface of activated carbon. They reduce the pH of the water.

Turbidity

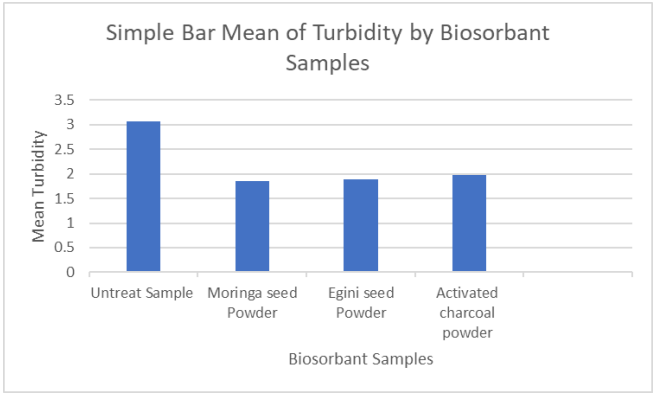

Fig. 2. Mean of Turbidity change

The anionic polyelectrolytes found in S. potatorum seeds are thought to be responsible for their coagulation qualities. These are molecules that have free hydroxyl groups (OH) on their surface and carboxyl groups (COOH) throughout their structure. (Yadav et al. 2014). Reduce the turbidity value because of the resulting of the cationic proteins in the moringa seeds. (Zaid, A., Ghazali, S., and Qannaf, A. (n.d.) 2015) Activated carbon's adsorptive qualities and porous shape make it a highly effective tool for lowering turbidity in water samples. (Nowicki, H. (2016).

Conductivity

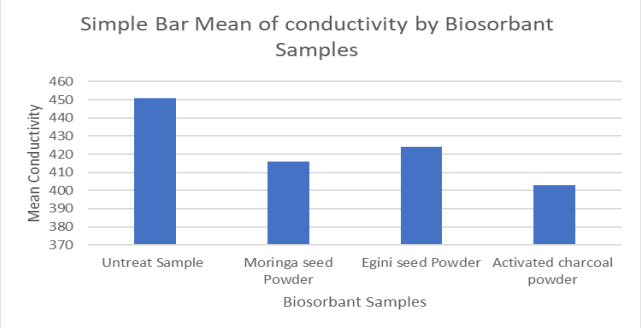

Fig. 3. Mean of Conductivity change

The seeds of *Strychnos potatorum* have natural coagulants in them. These seeds release coagulant proteins into the water, which causes colloidal particles and dissolved ions to become neutrally charged and assemble into bigger flocs. Sedimentation or filtration can then readily remove these flocs, lowering the EC and dissolved ion concentration. (Sharafi, R., Anam, N., Kamal, T., and Tazwar ST (2023). The solubility of minerals made possible by the seed proteins of *Moringa oleifera* is responsible for the treated water's drop in EC. These proteins have a net positive charge because of their amino groups, especially lower molecular weight water-soluble proteins.(Basra, S.M.A., Khan, Khalil-ur-Rehman, Hafeez-Ur-Rehman, and Ejaz, M.F. (2014). Electrical Conductivity (EC) readings may decrease in water samples treated with activated carbon for a number of reasons. Because of its enormous surface area and very porous structure, activated carbon can absorb ions and other chemicals from water.

Chloride

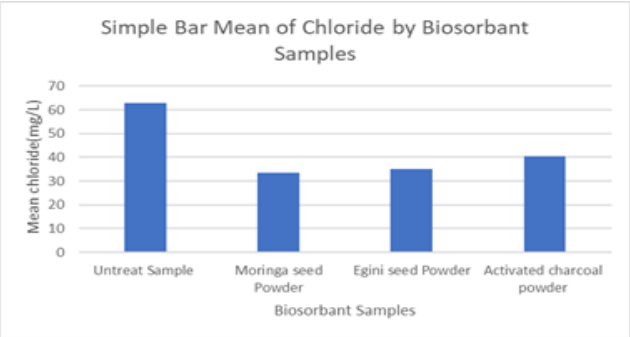

Fig. 4. Mean of Chloride change

These seeds encourage the aggregation of dissolved and suspended particles into bigger flocs when they are added to water. These flocs may consist of chloride ions (Cl^-), which are normally present in water as dissolved salts (e.g., NaCl). The content of chloride in the water drops when these flocs settle or are filtered off. Chloride ions are among the dissolved materials that can be adsorbed by the surface of *Strychnos potatorum* seeds and the flocs that they create. By reducing the amount of chloride ions in the water, this adsorption mechanism lowers the Cl^- value. (Unam.mx., 2014) The seeds of *Moringa oleifera* are rich in proteins, especially cationic proteins, which function as organic coagulants. These proteins balance the negative charges on dissolved ions, such as chloride ions, and suspended particles when they are added to water. Particles are encouraged to aggregate into bigger flocs by this neutralization(A.K., and Salama 2023). , activated carbon may also, albeit to a lower level, adsorb some inorganic ions, such as chloride. Chloride ions can be drawn to and retained on the surface of activated carbon, which lowers the concentration of these ions in the water. (Abouarnadasse, S. 2024).

Fluoride

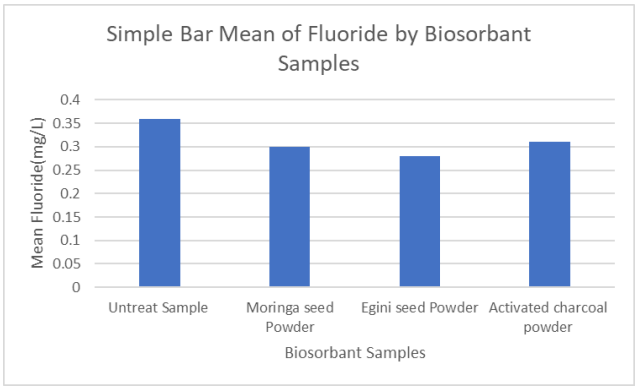

Fig. 5. Mean of Fluoride change

Drinking water samples had their fluoride successfully removed by *Strychnos potatorum*. Natural coagulants included in proteins and polysaccharides are released into the water by the seeds of *Strychnos potatorum*. (Rayappan, Jeyaprabha2014) The seeds of *Moringa oleifera* are rich in proteins, especially cationic proteins, which function as organic coagulants. These proteins balance the negative charges on dissolved ions and suspended particles, particularly fluoride ions when added to water. Particles are encouraged to aggregate into bigger flocs by this neutralisation. These flocs can absorb fluoride ions, which either filter out of the water or settle out of it, lowering the quantity of fluoride. (Gale Academic 2024 document) Because of its vast surface area and highly porous structure, activated carbon works well as an adsorbent for a variety of pollutants. Even though it is more frequently used to adsorb organic substances, activated carbon may also adsorb fluoride and other inorganic ions.

Hardness

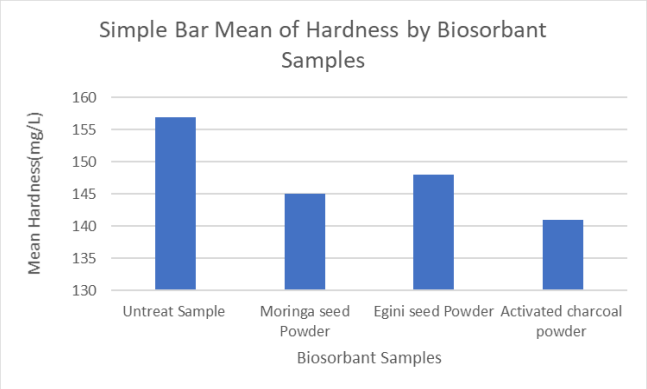

Fig. 6. Mean of Hardness change

When put in water, *Strychnos potatorum* seeds produce natural coagulants like proteins and polysaccharides. The charges on dissolved ions and suspended particles, such as the calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions that contribute to water hardness, are neutralised by these coagulants. (Kassim, A. 2014) Calcium and magnesium ions can be bound by the proteins and other substances that *Moringa oleifera* seeds release. These ions that cause hardness can be adsorbed on the surfaces of the flocs that are created during coagulation, which lowers the concentration of these ions in the water even more. . (Zaid, W., Eljak, E., Abdalsalam, H., Merghani, S., Elgeed, A., and Ali, B. (2023). Due to its high porosity and vast surface area, activated carbon can adsorb a variety of metal ions, including calcium (Ca^{2+}) and magnesium (Mg^{2+}), which are factors in the hardness of water. These ions cling to the activated carbon particles' surface, lowering the concentration of those particles in the water. (Manoilova, L. and Ruskova, K., 2022).

T. Ion

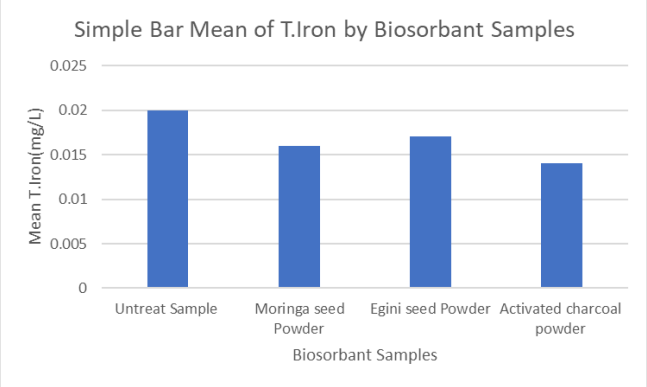

Fig. 7. Mean of T.Ion change

Natural coagulants found in *Strychnos potatorum* seeds, mostly proteins and polysaccharides, help suspended particles and dissolved ions in water aggregate(Nagaraja, K., Zo, S., Han, S.S., Rao, K.M., Hemalatha, D., and Rao, K.S.V.K. 2022)Proteins found in *moringa oleifera* seeds function as organic coagulants. These proteins balance the negative charges on dissolved ions and suspended particles in the water, especially a water-soluble cationic protein. .(A. Vieira (2010). Due to its vast surface area and very porous structure, activated carbon can absorb a variety of pollutants from the water, including iron ions. Because the iron ions are held in the pores of the activated carbon, the treated water contains less of them overall..(Manoilova, L. and Ruskova, K., 2022).

Phosphate

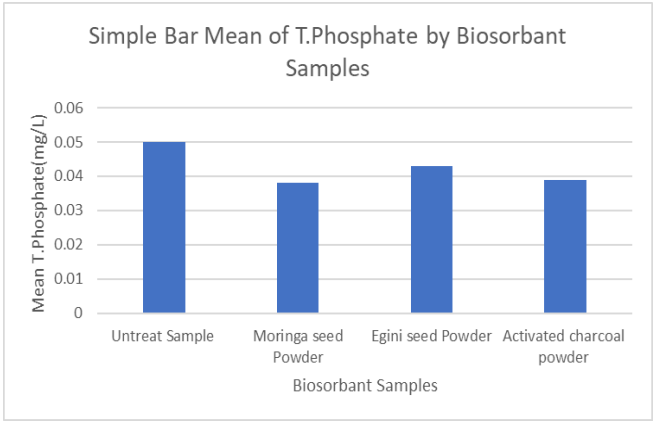

Fig. 8. Mean of Phosphate change

Proteins and polysaccharides, which are the main natural coagulants present in *Strychnos potatorum* seeds, help to aggregate dissolved substances and suspended particles in water. When used in water treatment, the natural coagulants in these seeds neutralize the charges on phosphate ions, causing them to flocculate, or cluster together, forming larger particles. Sedimentation or filtering, which may more easily remove these larger particles, can successfully lower the content of phosphate in the water (Kamal, T., Sharifi, R., Anam, N., and Tazwar, ST (2023). *Moringa oleifera* seeds contain natural coagulant proteins that are excellent in coagulating dissolved substances and suspended particles in water. These proteins counterbalance the negative charges of phosphate ions, causing the ions to flocculate, or gather together, forming larger particles.

Because removing these larger particles by filtration or sedimentation is easier, the amount of total phosphate in the water is reduced. (Elsergany 2023). Activated carbon has a large surface area and high porosity, providing numerous sites for the adsorption of various substances, including phosphate ions ($H_2PO_4^-$, HPO_4^{2-}, PO_4^{3-}). The phosphate ions are attracted to and held on the surface of the activated carbon particles, effectively removing them from the aqueous phase. Activated carbon surfaces contain functional groups such as hydroxyl (-OH), carboxyl (-COOH), and phenolic groups. (Lawtae, P. and Tangsathitkulchai, C. (2021).

Sulfate

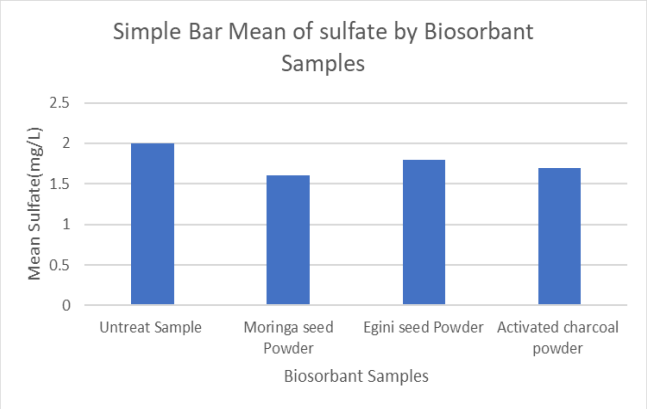

Fig. 9. Mean of Sulfate change

Strychnos potatorum seeds contain proteins and polysaccharides that act as natural coagulants. These substances neutralize the charges on sulfate ions (SO_4^{2-}) and other dissolved substances in water, causing them to clump together (flocculate) into larger particles. .(Sheeba, N.L., Esakki, E.S., Sarathi, R., Esaiarasi, A. and Sundar, S.M. (2023). *Moringa oleifera* seeds contain cationic proteins that act as natural coagulants. These proteins neutralize the negative charges on sulfate ions (SO_4^{2-}) and other dissolved substances in water, causing them to coagulate and form larger particles . .(Elsergany, M. 2023). Activated carbon has a large surface area and high porosity due to its intricate network of pores. Sulfate ions (SO_4^{2-}) are negatively charged and can be adsorbed onto the surface of activated carbon particles. The adsorption process involves electrostatic interactions, van der Waals forces, and hydrogen bonding between the sulfate ions and the functional groups on the activated carbon surface.

Nitrate

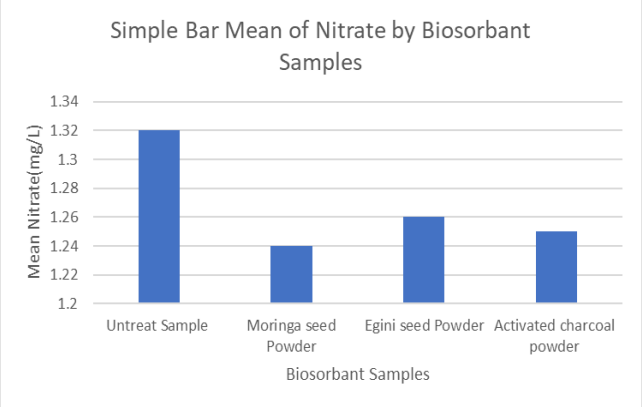

Fig. 10. Mean of Nitrate change

Strychnos potatorum seeds contain proteins and polysaccharides that act as natural coagulants. These substances can neutralize the charges on nitrate ions ($NO3^-$) and other dissolved substances in water, causing them to coagulate and form larger particle flocs. (Saif, M.M.S., Kumar, N.S. and Prasad, M.N.V. 2012). The ability of polyelectrolyte particles in *Moringa oleifera* seeds to reduce nitrate levels in drinking water is an intriguing aspect of its water purification capabilities. Polyelectrolytes are large molecules that contain many ionizable groups, giving them a net charge in solution. In the case of *Moringa oleifera* seeds, certain proteins and polysaccharides act as polyelectrolytes. .(Araújo, C.S.T., Carvalho, D.C., Rezende, H.C., S. Almeida, I.L., Coelho, L.M., Coelho, N.M.M. and Alves, T.L.M. and V.N. 2013) . Activated carbon has a highly porous structure with a large surface area. Nitrate ions ($NO3^-$) are negatively charged and can be adsorbed onto the surface of activated carbon particles. The adsorption process involves electrostatic interactions, van der Waals forces, and hydrogen bonding between the nitrate ions and the functional groups on the activated carbon surface. (Petrovic, B., Gorbounov, M. and Masoudi Soltani, S. (2022).

Nitrite

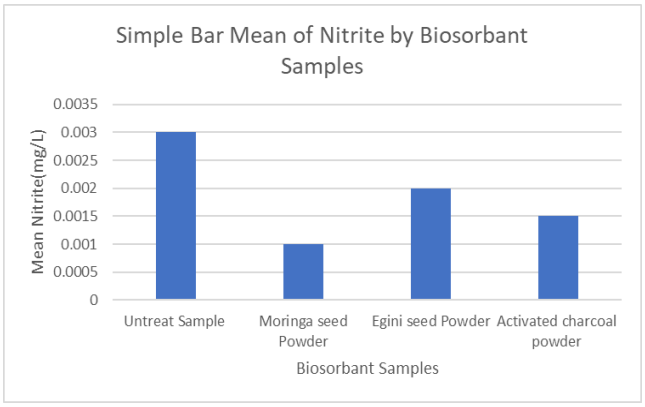

Fig. 11. Mean of Nitrite change

Strychnos potatorum seeds contain active compounds such as proteins and polysaccharides that act as natural coagulants. When these seeds are added to water, the active compounds neutralize the charges on suspended particles, including nitrite ions. This neutralization facilitates the aggregation of these particles into larger flocs. .(Salazar, J.M., Calle, J., Pereira, S., Cordero, P. and Matovelle, C. 2023). Moringa seeds contain water-soluble proteins that have strong coagulating properties. When added to water, these proteins neutralize the negative charges on suspended particles, including nitrite ions, facilitating the aggregation of particles into larger flocs (Araújo, C.S.T., Carvalho, D.C., Rezende, H.C., S. Almeida, I.L., Coelho, L.M., Coelho, N.M.M. and Alves, T.L.M. and V.N. (2013).

The reduction in nitrite value when treating a water sample with activated charcoal. Activated charcoal has a highly porous structure, providing a large surface area for adsorption. This large surface area allows activated charcoal to effectively trap and hold nitrite ions on its surface through physical adsorption (Pereira, J., Souza, R., Moreira, A. and Moita, A. 2024).

E. coli

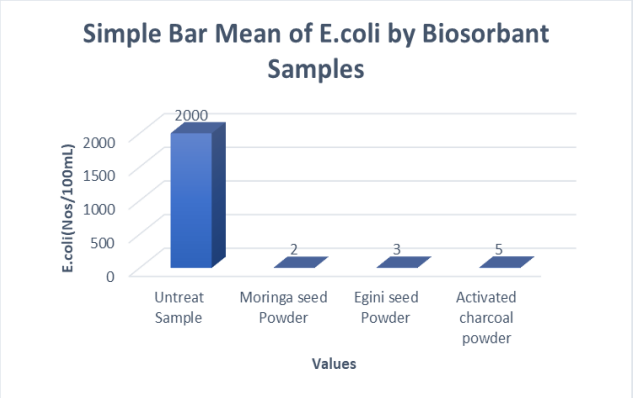

Fig. 12. Mean of E. coli change

The seeds of *Strychnos potatorum* are rich in proteins and other active ingredients that function as organic coagulants. By neutralizing the charges on suspended particles, such as E. Coli bacteria, these substances cause them to clump together into bigger aggregates, or flocs, when added to water. Water-soluble proteins found in *moringa oleifera* seeds function as organic coagulants. The large positive charge of these proteins balances the negative charge on the surface of E. Coli bacteria and other water-borne suspended particles. The highly porous nature of activated charcoal offers a large surface area for adsorption. Because of its enormous surface area, activated charcoal can physically adsorb E. coli germs to its surface, trapping and holding them there. The E. Coli bacteria are drawn to the surface of the activated charcoal particles and bond there throughout the adsorption process.

IV. Conclusion

The sample study's findings indicate that most of the parameters in the chosen water samples adhere to SLS stranded. most of the metrics in particular water samples. Although the *strychonos potatum* 60 mg/L, 10-hour water sample, *Moringa oleifera* 80 mg/L, 2-hour water sample, and 100 mg/L, 2-hour activated charcoal water sample were acknowledged to be reasonably accurate in terms of the water samples' physical, chemical, and biological SLS properties. As a result, the water samples that were most suitable for purifying the water's qualities were identified.

In accordance with the seed powders, physical, chemical, and biological characteristics were altered. The best seed powders were mixed with powdered activated charcoal, *Moringa oleifera*, *Strychonos potatum*, and Nuwara Wewa water sample. This study examined the water filtration capabilities of charcoal powder, *Moringa oleifera* seed powder, and Srychonos potatum powder. Following an analysis of the test findings, it was determined that activated charcoal, *Moringa oleifera* seeds, and Strychnos potatum seeds are excellent choices for purifying water. As a result, the local population can affordably and sustainably employ this technique to clean their water.

Acknowledgment

The author wishes to acknowledge the National Water Supply and Water Board Anuradhapura for the immense support and guidance given to overcome all the challenges and obstacles to complete the research successfully. Moreover, grateful to the Department of Biosystem and Biotechnology of SLTC Research University and all the academic members for providing us with adequate knowledge to make this a success.

References

[1] Ali, E., Muyibi, S., Salleh, H., Ramlan, M., Salleh, M. and Alam, M. (2009). MORINGA OLEIFERA SEEDS AS NATURAL COAGULANT FOR WATER TREATMENT. IWTC, [online] 13. Available at: https://core.ac.uk/download/pdf/300392141.pdf.

[2] Ali, B., Elgeed, A., Merghani, S., Abdalsalam, H., Eljak, E. and Zaid, W. (2023). EVALUATION [3].THE EFFICACY OF MORINGA OLEIFERA SEED POWDER ON PHYSICO-CHEMICAL PARAMETERS OF WHITE NILE RIVER WATER. International Journal of Science Academic Research, [online] 04, pp.5341–5346. Available at: https://www.scienceijsar.com/sites/default/files/article-pdf/IJSAR-1463.pdf.

[3] Applications www.ijera.com, [online] 4, pp.67–74. Available at: https://www.ijera.com/papers/Vol4_issue10/Part%20-%203/J410036774.pdf [Accessed 25 Jun. 2024]

[4] Araújo, C.S.T., Carvalho, D.C., Rezende, H.C., S. Almeida, I.L., Coelho, L.M., Coelho, N.M.M. and Alves, T.L.M. and V.N. (2013). Bioremediation of Waters Contaminated with Heavy Metals Using Moringa oleifera Seeds as Biosorbent. [online] www.intechopen.com. Available at: https://www.intechopen.com/chapters/45214.

[5] Badawi, A.K., Salama, R.S. and Mokhtar, M. (2023). Natural-based coagulants/flocculants as sustainable market-valued products for industrial wastewater treatment: a review of recent developments. RSC Advances, 13(28), pp.19335–19355. doi:https://doi.org/10.1039/d3ra01999c.

[6] Bakhta, S., Sadaoui, Z., Bouazizi, N., Samir, B., Allalou, O., Devouge-Boyer, C., Mignot, M. and Vieillard, J. (2022). Functional activated carbon: from synthesis to groundwater fluoride removal. RSC Advances, [online] 12(4), pp.2332–2348. doi:https://doi.org/10.1039/D1RA08209D.

[7] Basra, S.M.A., Iqbal, Z., Khalil-ur-Rehman, Hafeez-Ur-Rehman and Ejaz, M.F. (2014). Time Course Changes in pH, Electrical Conductivity and Heavy Metals (Pb, Cr) of Wastewater Using Moringa oleifera Lam. Seed and Alum, a Comparative Evaluation. Journal of Applied Research and Technology, 12(3), pp.560–567. doi:https://doi.org/10.1016/s1665-6423(14)71635-9.)

[8] Chauhan, S., Gupta, K. and Singh, J. (n.d.). PURIFICATION OF DRINKING WATER WITH THE APPLICATION OF NATURAL EXTRACTS. [online] Available at: https://www.mutagens.co.in/jgb/vol.04/1S/08.pdf.

[9] Dehmani, Y., Ba Mohammed, B., Oukhrib, R., Dehbi, A., Lamhasni, T., Brahmi, Y., El-Kordy, A., Franco, D.S.P., Georgin, J., Lima, E.C., Alrashdi, A.A., Tijani, N. and Abouarnadasse, S. (2024). Adsorption of various inorganic and organic pollutants by

[10] Desta, W.M. and Bote, M.E. (2021). Wastewater Treatment using a Natural Coagulant (Moringa oleifera Seeds): Optimization through Response Surface Methodology. Heliyon,7(11),p.e08451.doi:https://doi.org/10.1016/j.heliyon.2021.e08451.

[11] Elsergany, M. (2023). The Potential Use of Moringa peregrina Seeds and Seed Extract as a Bio-Coagulant for Water Purification.

Water, [online] 15(15), p.2804. doi:https://doi.org/10.3390/w15152804.

[12] Ghamande, M., Shinde, U., Chintawar, N., Chintawar, A. and Pawar, S. (n.d.). PURIFICATION OF WATER BY ACTIVATED CHARCOAL. [online] Available at:http://www.ijarse.com/images/fullpdf/1523544649_284IJARSE.pdf.

[13] Jeyakumar, P. (n.d.). National Conference on Green Engineering and Technologies for Sustainable Future-2014 Purification of pond water by natural seeds and dye water by synthetic coagulant. [online] Available at: charcoalhouse.com. (n.d.). Activated 14.Charcoal For Water Filters. [online] Available at: https://charcoalhouse.com/activated-charcoal-for-water-filters.

[14] https://www.jchps.com/specialissues/Special%20issue4/jchps%2019%20P%20JEYAKUMAR%2050-51.pdf [Accessed 25 Jun. 2024

Fashion, Textile and Clothing Technologies

Assessing the Effectiveness of Existing Marketing Strategies in Fashion Product Promotions: A Qualitative Study

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***Abstract*— Recent studies have highlighted the existence of dynamic marketing strategies in the Sri Lankan fashion industry within the broader economic context. Online media strategies proved to be important for apparel retailers during the COVID-19 pandemic, ensuring customer engagement and business continuity [1]. Accordingly, celebrity endorsements have been shown to help enhance brand image and drive sales in the local fashion retail chain [2]. Furthermore, strategies such as visual merchandising, ethnic appeal, patriotic marketing, and promotional pricing significantly impacted various retail segments including luxury apparel** [12]. **Although the price is attractive to consumers who are looking for affordable products, ethnicity in purchasing decisions in Sri Lanka, and the impact seems to be small [3]. This research aims to first evaluate the effectiveness of advertising strategies on consumer behaviours in the fashion industry in Colombo. Next, it seeks to examine the role of demographic factors (such as age, income, and gender) in consumer reactions to fashion advertising in Colombo. Finally, it aims to identify the challenges and opportunities for apparel retailers in Colombo in integrating traditional and digital advertising channels.**

Using a qualitative research method including interviews with semi-structured questions, this study focuses on industry experts such as fashion advertisers, photographers, designers, brand owners, retailers, and marketers' findings confirm how current advertising strategies (2018-2023) in Colombo deserve emphasis, with nuances of geography with the effectiveness of the COVID 19 situation and global influence. The result reveals the differentiations between demographical (age, profession) and geographical factors like urban and sub-urban differences and how they have affected results. Here considered the effectiveness of famous product promotional methods like social media and usage of visual merchandising methods with the voting from the majority. Investigating the effectiveness of different advertising methods will be focused according to the aims of this study. Identifying challenges and opportunities would be helpful with newcomers and existing brands and marketing people within the Sri Lankan Fashion industry.

Keywords—Sri Lanka Fashion Promotion, Retailers, Colombo, Marketing Strategies

I. INTRODUCTION/ LITERATURE REVIEW

The fashion Industry in Colombo, Sri Lanka's fashion capital is developing rapidly. Because various brands must continually adjust their advertising strategies to compete. And when consumer needs change understanding the impact of geographic and demographic factors is essential for effective marketing. This research explores the effectiveness of various advertising methods. It focuses on, how to tailor traditional and digital strategies to Colombo's diverse audience, by examining consumer behaviour observations, trust factors, and emerging advertising trends from the point of view of interviewees. The study aims to provide actionable insights, especially for fashion retailers looking to increase their efficiency.

A. Promotion:

Advertising is an important part of marketing, which is an active form of communication aimed at promoting products or services to consumers. In the fashion industry, advertising plays an important role in brand formation, engaging consumers, and influencing purchasing decisions. It is not just a way to inform consumers about new products, but it also provides important emotional connectivity and aspirations in a highly competitive and dynamic market [1]. This study examines various aspects of advertising in the fashion industry, focusing on the Sri Lankan context with the western province.

B. Importance:

Meaning and importance of advertising in fashion Advertising acts as a strategic communication strategy that not only promotes products but also establishes and reinforces the identity of brands. The importance of advertising in the fashion industry lies in its ability to increase brand visibility and consumer engagement. Celebrity endorsements, for example, are a powerful strategy that can increase brand visibility and consumer engagement by associating products with influencers, thereby enforcing brand intensity of interest [4], [2]. Moreover, effective advertising is crucial to maintain brand loyalty and ensure consistent market penetration. A study by Ebster and Garaus (2011) [5] highlights the impact of advertising on consumer attitudes and sales performance, which is particularly important for apparel companies aiming to capture consumer attention and maintain growth in a competitive environment [5], [3]

C.An overview of the Sri Lankan fashion industry:

The fashion industry in Sri Lanka is a dynamic and vibrant sector, marked by a variety of products including apparel, accessories, and footwear. The industry is located mainly in the western region, especially with Colombo acting as the sales hub for clothing stores. The market in Colombo is a mixture of local and international products, making it a place that balances traditional handicrafts with contemporary retail practices [13]. Several factors have shaped the market

growth in the Sri Lankan fashion industry, including local consumer preferences, cultural trends, and the growing influence of digital channels. With the rise of the middle class and the outflow of disposable income, the top levels have shifted into modern retail outlets. According to Hewage and Ranweera (2021) [2] this shift has opened opportunities for brands to distinguish themselves through new marketing strategies that cater to the evolving tastes and aspirations of Sri Lankan consumers. The impact of the COVID-19 pandemic on the industry has been significant, accelerating the transition to online marketing and causing companies to rethink their marketing strategies to compete in a rapidly changing environment [1]. This highlights the importance of e-commerce in changing market dynamics, providing new avenues for fashion designers to reach a wider audience [6].

D.Advertising strategies in fashion promotion:

Fashion brands use a variety of advertising strategies to effectively promote their products, each designed to drive consumer engagement and increase brand visibility in a highly competitive market. Internet marketing has become mainly about fashion advertising foundations, including e-commerce platforms, and Instagram. Facebook and other social media channels are key to reaching a wider audience and engaging consumers directly [1]. Social media campaigns, especially those involving influencer participation and content management, have proven to be highly effective in increasing brand visibility and credibility. These campaigns are especially acceptable among young social users' media, who are active on social media and value peer influence and authenticity in marketing [6]. In addition, celebrity endorsements are a powerful tool in fashion advertising. In the Sri Lankan context, local celebrity endorsements can significantly influence consumers' perceptions, increase brand credibility, and drive sales by associating products with well-known and trusted members of society [2]. Also, word-of-mouth strategies would give a warm feeling of trust [7].

E.Visual merchandising in fashion advertising:

Visual merchandising is another important advertising medium influencing consumer behavior by creating an engaging and immersive shopping experience. Creative displays in retail stores, including the effective use of colour, lighting, promotional signage, and placement, can have buy-in effects. Sentiment is a major influence on overall customer engagement. Research by Samarasiri and Tissera (2016) [8] shows that effective visual marketing strategies increase sales and enhance customer experience in retail. Similarly, Rathnayake, and Madhuhansi (2017) [9] found that attractive retail outlets play a significant role in attracting customers and influencing their purchase decisions [3]. A combination of several advertising strategies has proven to be highly effective in driving traffic and increasing impact. Online marketing, celebrity endorsements, and visual merchandising combine to enable fashion brands to develop cohesive and comprehensive marketing strategies that match the variety of consumer touchpoints. Studies conducted on Sri Lankan fashion brands showed targeting the strategy of social media advertising, [10] Celebrity endorsement channels and highlighting in-store displays were added, and up to 30 % came to online sales within three months [11]. This multi-faceted approach is especially important in the fashion industry, where trends are fast-paced and customer preferences are ever-changing [12], [11].

F. Challenges and Opportunities in Fashion Advertising in Sri Lanka

The Sri Lankan fashion industry faces many challenges, including increasing competition, changing consumer preferences, brands having to adapt digital marketing channels, and influential social media influencers and peer recommendations rather than the increasing traditional celebrity endorsement [6]. Furthermore, presenting opportunities and challenges for local brands, more emphasis is placed on sustainable and ethical clothing Maintaining competitiveness while adhering to sustainable practices is important for the industry development [12], [11]. The intersection of traditional and contemporary influencers, along with the increasing convergence of digital platforms, is positioning the industry for growth and innovation in the coming years [13], [11].

In summary, effective fashion promotion in Sri Lanka depends on strategic promotional strategies. Every channel from online marketing and social media campaigns to celebrity endorsements and visual marketing plays an important role in increasing brand visibility and consumer engagement These advertising channels can effectively lead fashion brands to adopt multiple channels, of traditional advertising. By integrating and leveraging strategies into today's digital channels, brands can create a unified and comprehensive shopping experience that appeals to consumers across multiple touch points. This comprehensive study paves the way for further research on the interaction between advertising strategies and consumer behavior in the fashion industry especially in the context of Sri Lanka Future research can go further to improve the quality of promotional efforts to increase customer engagement and brand performance.

*Objectives of the study***:**

1. To evaluate the effectiveness of advertising strategies on consumer behavior in the fashion industry in Colombo.
2. To examine the role of demographic factors (such as age, income, and gender) in consumer reactions to fashion advertising in Colombo.
3. To identify the challenges and opportunities for apparel retailers in Colombo in integrating traditional and digital advertising channels.

II. METHODOLOGY

A. Research Criteria

This study aims to identify the effective strategies of fashion advertising to promote fashion products in Colombo, Sri Lanka under the identified research questions. The survey targets fashion designers, retailers, and brand owners, who

have worked as professionals within the Fashion industry for more than 04 years.

Research Questions:

1. How effective are different advertising strategies (e.g., billboards, newsletters, e-advertising, word of mouth, visual marketing) in influencing consumer behaviour in the fashion industry in Colombo?
2. How do demographics such as age, income, and gender influence consumer reactions to fashion advertising in Colombo?
3. What are the key challenges and opportunities for fashion retailers in Colombo in combining traditional and digital advertising channels to increase brand visibility and consumer engagement?

B. Participants

The study had 31 participants including fashion experts in Colombo. These participants provide a comprehensive view of the fashion and advertising landscape in Colombo.

Table no 01: List of Participants *(respondents)*

Respondent Number	Role in the industry	Work experience in the industry
R01	Fashion Photographer, Advertising Firm Owner	50 years in Sri Lanka and abroad
R02	Tailor, Designer, and Owner of retail shop	15+ years
R03	Fashion Designer, Brand Owner, Stylist	8+ years
R04	Designer, Visual Merchandiser	7 years
R05	Fashion Journalist	5 years
R06	Clothing factory Owner, Brand owner, Merchandiser	20+ years
R07	Brand Owner, Factory Owner, Fashion Designer	6 years
R08	Retail Owner, Tailor, Designer	18 years
R09 *	Digital Marketing Specialist, Fashion Brands	10 years
R10	E-commerce Manager, Fashion Retailer	8 years
R11	Fashion Journalist, (Lifestyle Magazine)	12 years
R12	Visual Content Creator, Advertising Agency	9 years
R13	Social Media Influencer, Fashion Industry	5 years
R14	Retail Chain Manager, High-Street Fashion	15 years
R15	Advertising Copywriter, Fashion Campaigns	7 years
R16	Creative Director, Fashion Advertising	14 years
R17	Visual Merchandiser, Luxury Fashion Retailer	6 years
R18	Fashion Brand Manager, International Label	13 years
R19	Fashion Stylist, Freelance	8 years
R20	Owner, Independent Fashion Boutique	5 years
R21	Editor, Fashion Blog	10 years
R22	Branding Consultant, Fashion Startups	9 years
R23	Fashion Photographer, Freelancer	7 years
R24	Online Retail Specialist, Fashion E-commerce	6 years
R25	Public Relations Officer, Fashion Events	11 years
R26	Retail Strategy Consultant, Fashion Brands	15 years
R27	Content Creator, Fashion Vlog	4 years
R28	Advertising Director, Fashion Campaigns	8 years
R29	Fashion Blogger, Social Media Personality	6 years
R30	Fashion Retail Analyst, Market Research Firm	9 years
R31	Fashion Brand owner	4 years

C. Data Collection Methods

The research adopted a qualitative approach and conducted 31 interviews with fashion experts, exploring their experiences with different advertising strategies and their effectiveness within the Colombo area.

D. Data Analysis

Data were analyzed using a thematic analysis strategy, which helped identify key themes and patterns associated with effective fashion advertising strategies. Findings will be presented in narrative descriptions, tables, and charts for clarity.

E. Ethical Considerations

Data collection happened by securing, the identification of the interviewees and their organizational identities, and within every interview session, all interviewees were aware of the procedure with proper transparency.

F. Data Collection Timeline

The study was planned for over 2 years, with interviews within several months during and after COVID 19 period months, and a second round of data collection throughout the data analysis will be conducted in the fall on the eleventh and the final report will be ready by the end of the month the thirteenth month.

G. Pilot study

3 experts also participated in a pilot test to refine the interview guide and the flow of the survey instrument. The

data generated during the evaluation were used to improve evaluation methods and tools.

III Results

The result section has been presented under three research questions which have already been identified under the literature review separately.

3.1 Fashion Advertising Strategies in Colombo

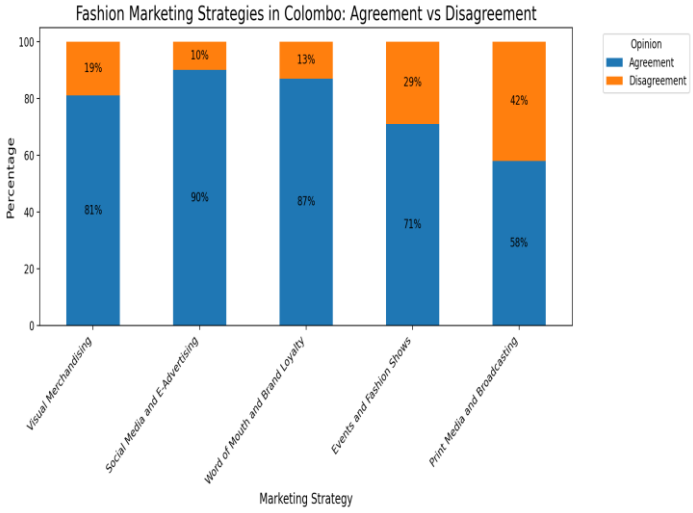

Figure 01: Agreements and disagreements regarding Fashion marketing strategies within the Colombo area

Participant Overview:

Participants represented different and relevant roles in the industry, enriching the analysis with a wider range of experiences and perspectives which revealed the geographical and demographic diversity of participants in Colombo and allowed for a comprehensive analysis of the effectiveness of fashion advertising strategies among different segments of the Colombo population with different perspectives.

1) Research Question 1- How effective are different advertising strategies (e.g., billboards, newsletters, e-advertising, word of mouth, visual marketing) in influencing consumer behaviors in the fashion industry in Colombo?

3.1.1 Visual Merchandising:

Agreements: The Majority of participants as interviewees agreed that the visual merchandising approach is more effective, especially in the busy commercial areas of Colombo. Window attraction and in-store layout were proven to increase foot traffic as an effective investment. "Customers would be enjoying window shopping maybe than purchasing the product and they like to visit the places which have the most attractive visual merchandising show casings" (R01, R06, R21), it's well connected with mindsets and satisfactions to lead the purchasing decision.

Disagreements: A few, mostly from smaller emerging companies, expressed concerns about the high costs associated with running premium stores in locations where they stand out, which can be a barrier to fresh start-ups, especially with investment. "People are aware of the quality and the trust with proper brand loyalty and don't have to waste money on visual merchandising" (R08).

3.1.2 Social Media and E-Advertising:

Agreements: Almost every participant highlighted the importance of social media for Colombo's young and tech-savvy audience. Instagram and Facebook were specifically mentioned as powerful ways to engage customers and drive sales. "Have to expect the fact that era is being converted and transformed, with the usage of digital media it's very possible to do anything, especially with social media, when considering marketing in both negative and positive manner" (R03, R04, R05, R07, R09, R10, ...) it's something already visible within the society in every side.

Disagreements: very few participants, especially from traditional retail, were sceptical about the reach of e-advertising, expressing concern that it might not target people as a large number of older people who are less active on social media. "it's like making chaos and twisting the decision of purchasing by all having so many details within a small time and having the digital devices all the time with the customer is not that much practicable" (R08, R18), with seniors, it's not that much possible to adjust the lifestyle of mixing with digitalization procedures.

3.1.3 Word of Mouth and Brand Loyalty:

Agreements: excluding 04 participants majority of participants agreed that word of mouth is an important factor in the Colombo fashion industry, especially in local fashion brands. "still people would depend on trust when they are purchasing especially when it's considered high-priced products, with the recommendations, rechecking, people could refer different strategies like social media and printed media also but consumers are willing to get confirmed with word of mouth from their trustworthy circles and well recommended public figures" (R01, R02, R03, R05, R06, R11, R14, R20, R21, R25, ….) when considering strong customer relationships and personalized service were identified as key factors in organic promotional strategies for fashion products especially when getting confirmed regarding purchasing decisions.

Disagreements: very few participants felt that word of mouth alone is not enough in a market where digital advertising is becoming more prevalent, and stressed the need for a balanced approach to emphasize great desire. "There are so many introverts within the society they are not willing to have so many interactions with others, especially before making a purchasing decision, even whatever it costs." (R10, R11, R29, R30) They were raising the psychological situations within current consumer segmentations.

3.1.4 Events and Fashion Shows:

Agreements: Nearly three-quarters of the participants supported the use of exclusive fashion shows and events as an effective advertising medium, especially for high-end products. These events were seen as important for brand reputation and communication with affluent consumers. "For a long time in Sri Lanka, high classy people with more spending power, especially those who like to express their statements are willing to participate in fashion shows and related events to buy exclusive products and connected with designers, and not only that but also those rich consumers are willing to show their statements by showing their fashion products which they purchased from designer brand for

higher prices." (R01, R03, R04, R05, R12, R15, R16, R17, R18, R22, R25, R28, R29...) This is considered as an interesting observation which happens for a considerable time within the market.

Disagreements: One of the three participants, mostly from small firms, shared concerns about the high cost as an investment and logistical difficulties of organizing such events. "it's taking so much time to organize events like fashion shows, especially when it's like start-ups it's really hard to manage the profit and continuity of the brand" (R06, R10, R13, R17, R24, R27, R31...) and they questioned their return on investment, especially for low-income innovations especially fresh start-ups.

3.1.5 Print Media and Broadcasting:

Agreements: The majority (More than half) of the respondents have agreed that traditional media such as newspapers and magazines still have value, especially for older consumers who may be less likely to participate in digital platforms. "People still would be depending on the hand feel and keeping them in in their library as memories not just to get the decision of purchasing" (R01, R02, R06, R08, R09, R11, R14, R16, R18, R21, R 26...) The majority of senior participants were raising the emotional value which has already bonded with the collecting and hand feel of the promotional materials.

Disagreements: Less than half of the participants, mostly from younger or digital-focused companies, said print media is becoming obsolete, and doesn't produce that much engagement or measurable results like digital advertising especially when considering the majority of the active population during decision-making. "Nothing to be surprised about in recommending more usage of digital media, because current most active generations are observing the usage of both printed media and digital media in a balanced manner with the observations and effectiveness, usage of printed media for promotion is such a waste and people don't like to keep the materials, especially like handbills" (R09, R10, R12, R13, R24, R27, R29,..)current generations are focusing on sustainability that would be considered as a good turning which could be considered environmentally.

3.2 Geographical and Demographic Considerations:

Research Question 2- **How do demographics such as age, income, and gender influence consumer reactions to fashion advertising in Colombo?**

3.2.1 Urban vs. Suburban: nearly three-quarters amount of the participants said that fashion advertising strategies should match Colombo's geographical diversity. "it's very natural to have different mindsets and perspectives depending on the exposure they are having. People would have exposure and experience according to their geographical situations, especially with facilities they have" (R01, R03, R04, R09, R10, R11, R12, R16, R17, R25, R26, R30...), This statement was marked by the majority of participants, especially with the infrastructure with internet and transportation. Urban areas with high density and high spending were found to be more receptive to modern, digital advertising strategies. In contrast, suburban areas were found to be better suited for combinations with traditional channels such as print media and personal events.

3.2.2 Demographic Factors: Instead of very few participants all of the other participants agreed that age, income, and culture play an important role in the effectiveness of advertising strategies the younger audience in Colombo tends to respond to social media campaigns, while older consumers still mostly prefer traditional media. "it's really hard to change the perspectives which people were having for a long time in their minds, and the mindset of people would be focusing on staying their comfortable zone most of the time" (R03, R05, R09, R10, R11, R13, R22, R25, R26, R29, R30, R31...) this was the summary from most of the young professionals and few senior professionals.

3.3 Challenges and Concerns:

Research Question 3- **What are the key challenges and opportunities for fashion retailers in Colombo in combining traditional and digital advertising channels to increase brand visibility and consumer engagement?**

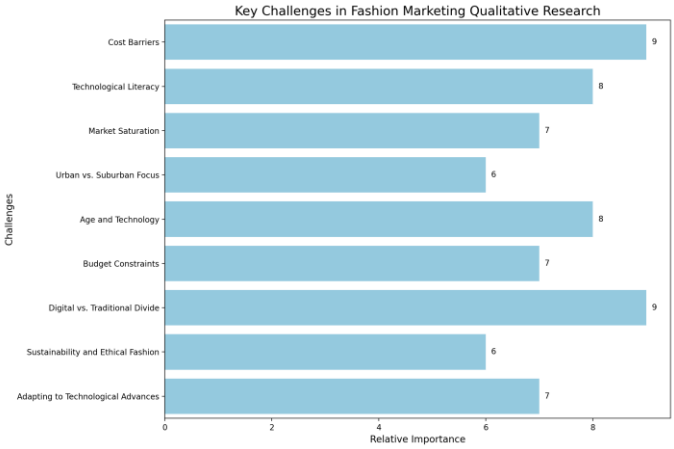

Figure 02: rates of specific challenges according to interviewees

3.3.1 Cost Barriers: Less than half of the participants expressed concern about the high costs associated with modern advertising strategies, such as digital campaigns and events, which can be prohibited for emerging subsidiaries.

R02: "Running a steady online and marketing campaign is some distance beyond our finances. We can't compete with the larger brands which could put money into those structures often."

R17: "As a new logo, allocating resources for both traditional and digital advertising is not possible. We're compelled to prioritize, and often, digital campaigns seem too high priced."

R23: "While virtual ads are powerful, they come with a charge tag that small groups can't have the funds for continually."

3.3.2 Technological Literacy: Less than 10 respondents highlighted the challenge of technological literacy among some sections of the Colombo society, especially older consumers, which limits digital advertising channels.

R12: "Many older consumers in Colombo are not yet engaging with social media or online advertising. They rely on publications or word of mouth to keep them updated on fashion."

R06: “Digital advertising works well with younger consumers. However, the older generation still faces problems with technology. This makes it difficult to fully transition to a digital strategy.”
R26: “We noticed clear differences across age groups. How do you respond to our digital campaigns? Older customers still rely on traditional methods.”

3.3.3 Market Saturation: More than 10 respondents shared concerns about digital platforms being cluttered with advertising material, making it difficult for individual brands to stand out without capitalizing on campaigns in a targeted.
R09: “Social media is full of advertisements. Our posts will get lost in the clutter. Unless we pay to have clear visibility.”
R18: “We tried digital advertising. But there is intense competition. It's hard to attract attention when everyone advertises the same way.”
R15: “Targeted campaigns are essential. Because otherwise, smaller brands can easily get lost in digital content.”

3.4 Participant Contributions and Perspectives

The geographical and demographic diversity of participants provided nuanced insights into the fashion advertising landscape in Colombo:

3.4.1 Urban Perspectives: Participants from more urban areas (e.g., store managers in the central areas of Colombo) tended to be more supportive of modern advertising strategies, whereas urban operators with smaller ones appeared to prefer the traditional methods.
R05: “Digital advertising and social media campaigns work best in the heart of Colombo. Our customers expect modern, trendy advertising.”
R21: “We have tried digital advertising. But for small businesses like ours, Traditional methods such as magazines or local events produce better results.”
R11: “It is important to adapt to customer needs. Urban transformation is moving towards digital.”

3.4.2 Age and Technology: Younger participants (below 35 years old), especially those involved in social media marketing, strongly recommended digital advertising, while older participants (above 35 years old) including some from established companies expressed a preference for print media and in-person strategies.
R16: “We rely heavily on digital marketing. It's faster and provides measurable results. Especially for younger viewers."
R04: “I still believe in the power of print and personal advertising. These methods are more effective for mature markets.”
R07: “Social media is where our younger customers are. So, we invested in it. But for old customers Traditional methods still have value.”

3.4.3 Budget Constraints: Many new start-ups as fashion brand owners expressed concerns about the high cost of consistent advertising across both digital and traditional platforms as investments.
R14: “We want to use both digital and traditional platforms. But the cost of regular advertising on both sides is too high.”
R31: "For start-ups, there is a choice between quality and quantity in advertising. Unfortunately, we cannot afford both.”

3.5 Emerging Trends and Future Directions

The study highlights emerging trends and areas of concern that could determine the future of fashion advertising in Colombo:

3.5.1 Digital vs. Traditional Divide: The effectiveness of advertising channels is highly dependent on the target demographic, with a clear divide between digital and traditional channels Participants from different age groups and backgrounds emphasized the need for a balanced approach taking into justification the unique characteristics of Colombo’s diverse population.
R01: “We still need a digital and traditional strategy. Younger customers engage with online advertising. But older customers still prefer print.”
R22: “It's not about choosing one way or the other. Colombo's diverse population means we have to balance both advertising methods."
R08: "For the widest audience We need a mix of digital and traditional channels that cater to different demographics.”

3.5.2 Sustainability and Ethical Fashion: from the sample, more than half of the participants observed growing consumer interest in sustainability, which is beginning to find its way into advertising channels' influence. Brands emphasizing especially ethical and environmentally friendly materials are gaining momentum, especially among young, socially active consumers.
R10: “Sustainability is not a choice. Our young customers will ask about this. And this influences their purchasing decisions.”
R28: “We have noticed a growing interest in ethically produced fashion. This is something we are considering integrating more into our brand.”
R25: “Advertising sustainable and ethical products can position brands in today's market. Especially for socially conscious consumers.”

3.5.3 Adapting to Technological Advances: As technology continues to evolve, almost more than half of the sample identified the importance of staying well-informed of the latest digital marketing trends, including consuming big data use of personalized marketing, and the potential for augmented reality (AR). marketing that enhances the experience.
R13: “Personalized advertising is the future. Big data helps us target the right customers with the right message.”
R27: “We are exploring augmented reality for virtual reality initiatives. It is innovative and can increase customer engagement.”
R03: “Keeping up with digital trends is important. The market is changing rapidly. And brands that don't adapt will be left behind.”

These insights highlight the complexity of the fashion advertising landscape in Colombo, where geographical and demographic factors, as well as economic constraints, and changing consumer preferences, play a significant role in shaping advertising strategies and the effectiveness of the species.

IV DISCUSSION

Analysis of fashion advertising strategies in Colombo provided important insights into the effectiveness of strategies considering geographical demographic factors affecting consumer behavior All respondents gave nuanced reasons for the challenges and opportunities faced by fashion advertising in this dynamic market and identified possible directions for future research.

4.1 The Influence of Geographical and Demographic Factors on Advertising Effectiveness

Demographic differences among stakeholders played an important role in shaping the effectiveness of advertising strategies. This is consistent with existing literature, which emphasizes the importance of tailoring marketing efforts to specific local demographic conditions [1], [2].

4.1.1 Urban vs. Suburban Preferences: The majority of participants from urban areas were more interested in modern advertising channels such as digital e-advertising, whereas those from small towns (Less than one out of three samples were from small towns). Traditional methods such as print and word of mouth are the best [3]. This has been noted as the effectiveness of different advertising strategies based on local content.

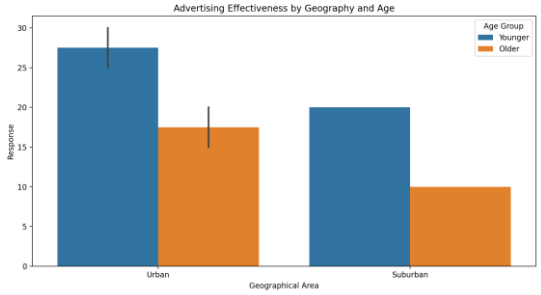

Figure 03: Segmentation of participant responses based on geographical areas *(urban vs. suburban)* and demographics *(age and income levels)*.

This figure highlights the differences in advertising effectiveness across these segments.

4.1.2 Age and Income Level: Most of the younger participants and higher income groups responded positively to digital marketing channels, while the elderly and those from low-income groups People prefer traditional media. This demographic segmentation is very important in designing an effective advertising campaign [6].

4.2 Challenges and Concerns in Fashion Advertising

The study also identified several challenges and concerns related to advertising strategies, especially for small emerging fashion brands These challenges were discussed by a significant number of respondents in line with findings in the literature on finance and technological barriers in modern business are consistent [11], [12], [6].

1. **Cost and Accessibility:** Few Respondents highlighted the high costs associated with consistent advertising across digital and traditional platforms. Small businesses, in particular, struggle to allocate enough resources to this effort [3].

2. **Technological Literacy:** Several respondents expressed concerns about the technical skills required for effective digital advertising, especially with consumers who are elderly and from low-income families. This concern is consistent with the digital divide observed in emerging markets [6].

4.3 Recommended optimizing methods:

These recommendations aim to optimize the effectiveness of fashion advertising strategies in Colombo, ensuring that brands can adapt to changing consumer preferences and market dynamics.

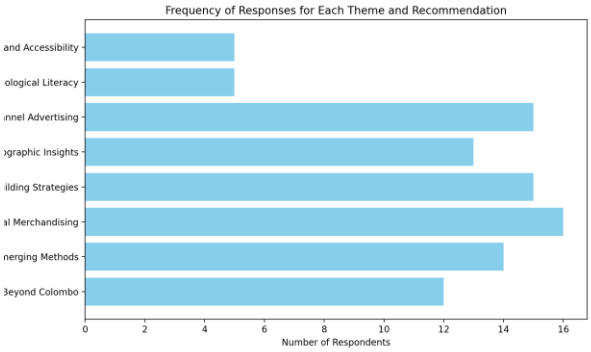

Figure 04: the frequency of responses for each theme and recommendation.

1. **Adopt a Multi-Channel Advertising Approach** The majority of respondents supported the integration of traditional and digital advertising channels, brands through billboards, media advertisements, and word-of-mouth strategy, and social media campaigns. Organizations can communicate with a wider audience, satisfy diverse consumer preferences, and develop stronger brand awareness and trust [2].

2. **Leverage Demographic Insights for Targeted Advertising**
nearly half of the samples as respondents highlighted the importance of tailoring advertising strategies based on demographics such as age, income, gender, and social status through specific ad content and consistency with category each match, brand engagement and conversion rates enhance, resulting in more personalized and effective marketing efforts [1].

3. **Focus on Trust-Building Advertising Strategies** almost half number of Interviewees emphasized the importance of emphasizing advertising strategies that build consumer trust, such as word-of-mouth marketing and visual marketing. In online

advertising, ensuring that clear and accurate product information is presented is important to build consumer confidence, especially in the Colombo market, where personal recommendation greatly influences purchasing decisions [6].

4. **Enhance Visual Merchandising Techniques**
   Half of the respondents recommended investing in new visual marketing strategies to attract attention and encourage in-store browsing. Window displays, store layouts, and product displays to reflect current fashion trends can significantly increase foot traffic and sales [8].

5. **Explore and Implement Emerging Advertising Methods**
   Less than half of the respondents from the sample suggested staying aware of global advertising issues and looking at their application in the Sri Lankan context. The demand for new digital platforms, influencer marketing, and immersive technologies such as augmented reality (AR) can also allow brands to stand out in a crowded marketplace, ensuring they remain competitive and innovative [12].

6. **Expand Fashion Advertising Beyond Colombo**
   Less than half of the respondents from the sample recommended expansion of advertising efforts to other cities and semi-urban areas in Sri Lanka. Market research to identify areas with high growth potential can help brands penetrate new markets, increase their customer base, and increase market share [13].

Supported by data from various interviewees, these focused recommendations aim at effective fashion advertising in Colombo, enabling brands to adapt to consumer preferences changing preferences and compete in emerging markets.

V CONCLUSION

The research highlights the important role of geographic and demographic factors in determining the effectiveness of fashion advertising strategies in Colombo. As the fashion capital of Sri Lanka Colombo presents challenges and opportunities for brands. who are looking to thrive in a rapidly changing environment Findings from 31 respondents suggest a tailored, Omni-channel advertising strategy. It combines traditional methods such as print and word of mouth with modern digital platforms. Critical to reaching Colombo's diverse customer base, the main view highlights those urban consumers are likely to be more receptive to digital channels. Meanwhile, suburban and low-income groups still prefer traditional advertising methods. This finding is consistent with the work of Karunasekara (2021) [3] and Weerakoon (2021) [6], who linked advertising methods with local consumer demand and technological knowledge The importance of the mine has been recognized, and trust remains a key factor. Word of mouth and Visual Merchandising in stores have a huge influence on consumers' purchasing decisions, especially in Colombo's established fashion market.

Emerging advertising methods such as influencer marketing and augmented reality (AR) are recommended for future exploration, especially within the fashion industry which is already entering the market. Their ability to increase engagement is evident from global trends. It shows that brands in Sri Lanka can benefit from combining these strategies [12].

Additionally, expanding advertising efforts beyond Colombo can help fashion retailers break into new markets. This has led to the growth of the industry throughout the country [13].

In the end, fashion brands in Colombo should take a multi-channel approach to building trust. It leverages demographic insights to tailor strategies to adapt to emerging global trends and expand reach. These brands will be well-positioned for long-term success in an increasingly competitive landscape.

ACKNOWLEDGMENT

My sincere gratitude goes to all those who contributed to this study and helped in the successful completion of this study. I am grateful to the 31 interviewees who generously shared their experiences and insights, making this research possible.

REFERENCES

[1] R. Pathirana and T. Ranaweera, "The evolution of advertising strategies in the fashion industry," 2023.

[2] C. Hewage and T. Ranaweera, "The influence of celebrity endorsements in Sri Lankan fashion advertising," 2021.

[3] H. Karunasekara, "The role of visual merchandising in retail environments," 2021.

[4] C. Schlecht, "The power of celebrity endorsements in advertising," 2003.

[5] C. Ebster and M. Garaus, "The impact of advertising on consumer perceptions and sales performance," 2011.

[6] D. Weerakoon, "The impact of social media on consumer behavior in the fashion industry," 2021.

[7] U. C. Rathnayake, "Advertising methods in fashion promotion," 2023.

[8] S. Samarasiri and M. Tissera, "Effective visual merchandising techniques in retail environments," 2016.

[9] U. Rathnayaka et al., "The impact made by visual merchandising elements on purchase intention: With special reference to supermarket industry in Western Province," *International Journal of Scientific and Research Publications*, vol. 7, 2017. [Online]. Available: https://www.researchgate.net/publication/319644937

[10] R. Gajanayake et al., "The impact of visual merchandising on consumer choices within the Sri Lankan retail sector," 2011.

[11] A. Gopura, "Case study on a Sri Lankan apparel brand's advertising strategies," 2023.

[12] M. Ishi, "The shift towards sustainable practices in the Sri Lankan fashion industry," 2021.

[13] H. Karunasekara, "Overview of the fashion industry in Sri Lanka," 2007

Enhancing Sustainable Development Through Post-Consumer Textile Waste Recycling: Improving Human Well-being

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***Abstract*— This research explores the important role of textile recycling in promoting sustainability and improving human welfare, while also offering actionable suggestions for improvement. The study employs both qualitative and quantitative analysis, including interviews and surveys, to highlight the environmental and social benefits of effective textile recycling. The findings underscore the necessity of integrating sustainable practices with consumer behavior and industry standards to foster a circular economy. Ultimately, this research aims to contribute to a broader discourse on sustainable development and emphasizes the importance of responsible consumption within the textile industry.**

Keywords: Textile Recycling, Sustainable Development, Human Well-being, Consumer Awareness, Circular Economy.

I. INTRODUCTION

The textile industry, encompassing the apparel and fashion (TAF) sectors, represents a complex global supply chain spanning many stages from fiber production to ready-made clothing and retail. It is the third largest employer in the world and plays a crucial role in raw material usage and resource management. As noted by the European Environment Agency (EEA) in 2023, the urgency of sustainability in this sector is underscored by the culture of fast fashion, which promotes rapid turnover of apparel, leading to significant waste and environmental degradation [1]. Business practices in TAF must evolve to meet current sustainability needs while ensuring long-term environmental and social well-being. This includes conserving resources, reducing pollution, minimizing waste, and promoting responsible consumption and production. This research aims to explore new strategies to reduce post-consumer textile waste, which is often disposed of alongside inorganic waste, ultimately ending up in landfills or incineration [2].

OBJECTIVES

• To evaluate demand for post-consumer textile waste in textile-to-textile recycling.

• To assess the challenges and economic feasibility of recycling post-consumer textile waste.

• To emphasize the importance of recycling in reducing pollution.

By achieving these objectives, the research aims to provide a comprehensive understanding of the dynamics surrounding post-consumer textile waste and contribute to the development of effective strategies for fostering sustainability in the textile industry.

A. Environmental Impact of the Textile and Fashion Industry

The textile and fashion industry is one of the most environmentally damaging and resource-intensive sectors, driven by a surging global population. Its extensive use of water, energy, and chemicals severely impacts the natural environment, exacerbating issues like greenhouse gas emissions and deforestation [3]. Particularly in European countries, the prevalent "buy-and-throw-away" culture has led to a staggering increase in clothing consumption, positioning clothing as the fourth most environmentally detrimental area of consumption after housing, transportation, and food [4].

Cotton production presents its own set of environmental challenges; the extensive use of fertilizers and fuel in cotton farming significantly contributes to greenhouse gas emissions while deforestation and soil infertility exacerbate the environmental impact [5]. Conversely, synthetic textiles intensify environmental degradation due to the energy-intensive manufacturing processes involved in producing synthetic fibers like polyester, nylon, and acrylic, which surpass those of cotton fabrics [6]. Notably, synthetic textiles now comprise about 70% of global textile consumption [7]. Furthermore, the disposal of synthetic materials releases toxic pollutants into groundwater, compounding their environmental footprint [8].

The energy-intensive processes of washing, drying, and dyeing textiles contribute significantly to overall energy consumption due to the heavy machinery involved [9]. The business model prevalent in the TAF industries—characterized by high consumption, disposability, and limited recycling—has resulted in severe pollution and waste generation, making these sectors among the most polluting globally [10].

B. Sustainability

Current economic systems are based on rapid product Current economic systems, built on rapid product replacement, often overlook the need for long-term design [11]. Sustainable development is defined as meeting present

needs without compromising the ability of future generations to meet theirs [12]. The textile and fashion industries contribute approximately 8-10% of global greenhouse gas emissions, significantly impacting climate change [13].

Ranking second in land use, fourth in water use, and fifth in greenhouse gas emissions, the textile industry contributes 1.2 billion tons of greenhouse gases annually [14]. In response to these challenges, the United Nations introduced the Sustainable Development Goals (SDGs) in 2015, which encompass 17 global objectives focused on environmental sustainability, social inclusion, and economic development [15].

The concept of sustainability revolves around three interconnected dimensions: economic, environmental, and social—known as the triple bottom line [16]. This model is used to evaluate the environmental impact of textile businesses, while waste reduction and resource recovery are key goals within a circular economy [17]. However, energy recovery alone cannot fulfill the concept of a circular economy, necessitating the recycling or remanufacturing of textile waste [18].

Consumer adoption of sustainable fashion remains low due to a lack of awareness, despite growing interest in eco-friendly products [19]. Research indicates that consumers are often unwilling to pay for organic or recycled textiles due to concerns about quality and price [20]. Limited consumer knowledge and awareness about sustainability also act as barriers to sustainable clothing practices [21].

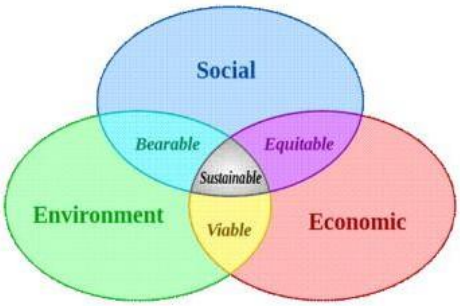

Fig 1: The "Three Pillars" of sustainability bounded by the environment
Source: Sustainable Development of Apparel Industry in Bangladesh: A Critical Review

Eco-certification can provide industries with a market advantage by improving product image and gaining access to eco-conscious consumers [22]. However, issues such as deceptive claims, lack of standardization, and unfair competition are common problems associated with ecolabeling [23]. Various standards have been established to guide sustainable practices, including ISO 14001:2015, ISO 14044:2006, and ISO 14046:2014, which outline life cycle assessments, environmental management systems, and water footprint guidelines [24].

C. *Textile Waste*

The expansion of the fashion industry and rapidly changing trends have significantly contributed to environmental problems, particularly as production extends to developing countries [25]. Textile waste, both pre-consumer and post-consumer, has become a major concern, with material costs accounting for a significant share of apparel expenses [26].

Post-consumer textile waste (PCTW) decomposing in landfills releases harmful gases like methane and carbon dioxide, contributing to climate change. Additionally, leachates from decomposing waste contaminate water sources, posing risks to human health [27]. The phenomenon of "denim dumping" highlights environmental injustice, with textile waste from wealthier regions disproportionately impacting less privileged areas [28].

Landfilling leads to habitat destruction and the permanent loss of raw materials, emphasizing the need for recycling and sustainable waste management [29]. The growing environmental concerns over waste accumulation and its impact on biodiversity and water pollution have underscored the urgent need for better waste management solutions [30].

D. *Textile waste Recycling*

The concept of fast fashion has made clothing a disposable product, with less than 1% of textiles being recycled into new garments [31]. This has resulted in 75% of textile waste ending up in landfills, creating a significant environmental challenge [32].

II. METHODOLOGY

This study employs a mixed-methods research design to address post-consumer textile waste management, combining both qualitative and quantitative approaches. Data was collected through surveys, interviews, and observations to gain a holistic understanding of the recycling landscape.

- Surveys - Two survey questionnaires collected demographic details and specific information on the role of stakeholders in the textile supply chain. Including opinions about purchasing recycled materials, challenges, and economic viability, and sustainable waste management 221 stakeholders participated in the apparel and recycling sectors. By providing quantitative information This was then analyzed through descriptive and inferential statistics via the SPSS version.
- Interviews - The interviews provided qualitative insights into barriers to recycling and stakeholder attitudes. Add depth to the study and gather perspectives on recycling practices.
- Observations - Observational methods provide additional qualitative information. It allows researchers to directly observe waste management practices. It provides contextual information about real-world processes.

III. RESULTS

This study aims to provide a comprehensive analysis of the data collected on post-consumer textile waste recycling. The results offer valuable insights into the needs, challenges, and economic feasibility of textile waste recycling, with an emphasis on the sustainability benefits of recycling post-consumer textile waste. It is a sustainable solution to reduce pollution and promote environmental management.

The general survey aims to increase understanding of consumer behavior in the sustainable clothing market and to

inform strategies that promote environmental stewardship and responsible consumption.

A. Consumer behaviour towards sustainable textiles across different age groups

The age distribution of the sample ranged from 18 to 64 years, with an average age of approximately 41 years. The distribution was fairly normal but slightly skewed to the right. This indicates good representation of various age groups. Especially the trend among younger and middle-aged respondents.

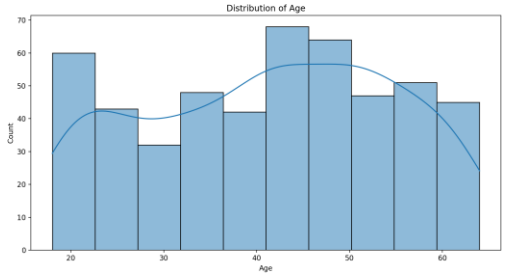

Fig. 2. Consumer Behavior in Sustainable Textiles

B. Purchase Frequency by Awareness of Waste

The study found that the purchasing frequency distribution was relatively uniform with annual buyers slightly decreasing. This reflects the participation of consumers in the fashion industry. Awareness about textile waste is nearly equal, with 48% aware and 52% not aware. This suggests that awareness may not have a significant impact on purchasing behavior. This is because both groups have a similar distribution of purchasing frequencies.

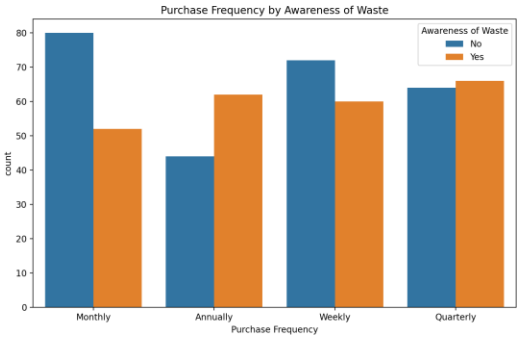

Fig. 3. Purchase Frequency by Awareness of Waste

C. Attitude Towards Sustainability by Income

The distribution of income remains relatively even across the ranks with a slight tilt towards the middle-income group Attitudes towards sustainability range from positive to negative with a slight inclination towards neutral and positive. Higher income groups (above $90,000) show a slightly higher proportion of positive attitudes towards sustainability. But all income groups have mixed attitudes. It suggests that income alone may not determine sustainability attitudes.

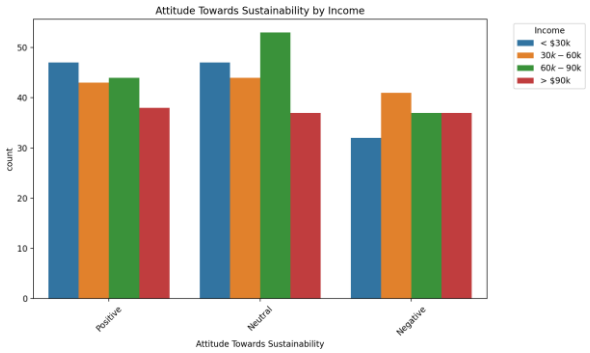

Fig.4. Attitude Towards Sustainability by Income

Overall, this data offers an analysis of consumer attitudes and behavior towards sustainability in the fashion industry. Emphasis is placed on demographic diversity. It was noted that individuals with higher incomes have more positive sustainability attitudes. However, there is a significant gap between awareness of sustainability issues and actual purchasing behavior. This indicates the need for effective strategies to stimulate action. This is despite the fact that many consumers express neutral or positive attitudes towards sustainability. But negative attitudes still present obstacles. The findings highlight the importance of targeted education campaigns. Improving access to sustainable fashion and tailored approaches for different consumer groups. To effectively promote sustainable practices, overall, analytics serves as the foundation for understanding and managing sustainable consumer behavior.

D. Attitude towards sustainability by age

The visualization analyzes the relationship between age and attitudes towards sustainability in fashion using logistic regression. They found a weak and not statistically significant relationship between age and positive attitudes with the predicted probabilities remaining narrow and consistent across age groups. Scatter plots indicate significant individual variation. It suggests that factors other than age are more influential in shaping attitudes towards sustainability. As such, these findings support a market-neutral approach for the fashion industry. Emphasis is placed on individual strategies and the need for further research on additional influencing factors.

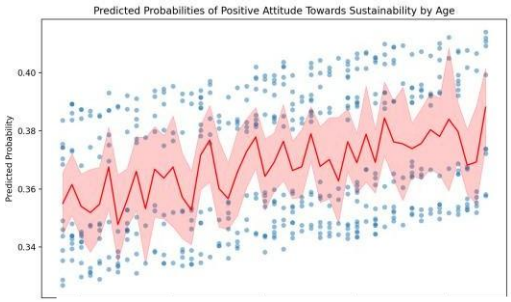

Fig. 5. Attitude towards sustainability by age

E. Addressing Consumer Perspectives and Industry Challenges

This research explores consumer perspectives and addresses the urgent need for sustainable practices within the textile industry as well as the challenges businesses face. Faced with implementing sustainable solutions by analyzing survey data that reflects the demographics and interests of the market. This study therefore adjusts strategies to effectively meet the diverse needs of different consumer groups.

It assesses the growing market interest in post-consumer recycled clothing and identify key barriers such as technological limitations, high costs, and supply chain challenges that impede progress. Despite these obstacles, companies are investing in innovative and cost-effective recycling technologies and procurement methods, trying to increase their success.

Research highlights environmental benefits of textile recycling. This shows the important role of promoting sustainability and environmental management. Although the shift towards environmentally friendly practices is evident. But progress remains slow due to factors such as cost sensitivities. Limited consumer awareness and limitations in operations.

Collaboration between consumers, businesses and stakeholders is essential to addressing these challenges. This will ultimately pave the way for a more sustainable future in the textile industry.

Meanwhile, the visualization shows a positive relationship between circular economy practices and sustainability impacts. This demonstrates the industry's commitment to reducing its environmental impact. At the same time, it acknowledges the complexities involved in achieving these goals.

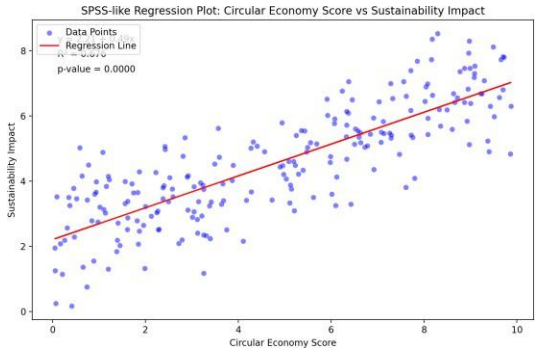

Fig. 6. Circular Economy Score and Sustainability Impact

IV. DISCUSSION

The research addresses important issues of post-consumer textile waste within the textile industry which has traditionally followed a linear consumption model. This highlights the urgent need for sustainable solutions to reduce the industry's environmental impact. especially through recycling. The literature review highlights various environmental challenges. Including the creation of waste, pollution and wastage of resources. Positioning recycling as a workable solution. with details of the main points.

A. Demographic Insights

The results of the survey revealed that the majority of respondents were younger. More than half are aged 21-30. This demographic trend shows that younger consumers' attitudes and behaviors towards sustainable clothing choices may be different compared to older generations. These findings point to a growing market demand for eco-friendly clothing products in this age group. This is important for businesses that want to tailor their offerings to meet consumer needs.

B. Gender Distribution

The gender distribution of respondents shows significant differences. with women being the majority. This highlights the need for gender inclusive sustainable clothing initiatives. Understanding the preferences and purchasing behaviors of different genders. It will help companies adjust marketing strategies and product presentations to better meet the needs of their target audience.

C. Socio-Economic Backgrounds

Analysis of the socio-economic background of the respondents reveals a wide distribution of monthly income. With a significant proportion earning less than R15,000 per month, this economic shift may affect attitudes towards sustainability. This is because price sensitivity is a barrier to choosing sustainable clothing. Many consumers express a desire to change their habits for sustainability, however, only a small percentage are willing to pay a premium for recycled clothing. This points to the need for strategies that make sustainable alternatives affordable and competitive in the market.

D. Consumer Attitudes Towards Sustainability

Survey reveals strong interest in sustainable clothing options among consumers especially for recycled materials. However, there is still a lack of awareness about practices for generating and recycling textile waste. This knowledge gap highlights the importance of education campaigns aimed at increasing consumer awareness of the environmental impacts of textile waste and the benefits of recycling. Companies can build trust and credibility with customers, consumers, and foster stronger brand loyalty.

E. Organizational Dynamics and Challenges

The survey also examined respondents' organizational backgrounds. This highlights the outstanding representation of mid-level professionals. Particularly in management roles within the manufacturing sector, organizations face many challenges when integrating post-consumer textile waste into production, including technological limitations. Supply chain problems and high costs Despite these limitations, there is strong commitment among organizations. Recognize the importance of long-term competitiveness and environmental responsibility.

F. Market Demand and Economic Feasibility

Research indicates strong market demand for sustainable and recycled textile products, however, the economic viability of recycling practices is a concern. This is because companies such as Arcadian Sourcing (Private) Ltd (ASPL) appear to be demonstrating that sustainable practices can provide economic returns by reducing environmental impact. Research highlights the importance of new approaches to increasing the economic viability of textile recycling. It points out that industry collaboration and cooperation can drive progress towards sustainability.

G. The Role of Education and Awareness

One of the most important points that emerged from the discussions was the need for education and awareness regarding textile recycling. Lack of consumer knowledge hampers efforts to achieve sustainable waste management practices. Bridging the knowledge and action gap is essential to promoting a culture of sustainability within the textile sector. Educational initiatives can encourage consumers to make informed choices and support various businesses Adopt more sustainable practices.

V. Conclusion

This study examines the current state of post-consumer textile waste recycling and consumer behavior towards sustainability. It reveals that while awareness of sustainability is increasing, significant gaps remain between consumer attitudes and actual behaviors. To bridge these gaps, a combination of education, economic feasibility, and industry innovation is essential.

The success of sustainable practices in the fashion industry relies on collaboration, innovation, and active consumer engagement. This research highlights the potential of post-consumer textile waste recycling as a viable solution for reducing pollution and enhancing environmental management. However, challenges such as price sensitivity and technological limitations persist, hindering progress in this area.

Overall, this study makes a significant contribution to the ongoing discourse on sustainable practices within the textile industry. It presents actionable recommendations for future improvements, including the need for educational campaigns aimed at raising awareness about textile waste and recycling. These initiatives should focus on bridging the gap between knowledge and practice to promote effective waste management strategies.

Acknowledgment

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References

[1] European Environment Agency, “Textiles in Europe's circular economy,” 2023. [Online]. Available: https://europa.eu.

[2] D. G. K. Dissanayake, D. U. Weerasinghe, L. M. Thebuwanage, and U. A. A. N. Bandara, “An environmentally friendly sound insulation material from post-industrial textile waste and natural rubber,” Journal of Building Engineering, vol. 33, p. 101606, 2021.

[3] NCM, “Economic instruments and separate collection systems,” 2015. [Online]. Available: [URL needed].

[4] European Environment Agency, “Economic instruments and separate collection systems,” 2024F. [Online]. Available: [URL needed].

[5] M. Bevilacqua, F. E. Ciarapica, G. Mazzuto, and C. Paciarotti, “Environmental analysis of a cotton yarn supply chain,” Journal of Cleaner Production, vol. 82, pp. 154-165, 2014.

[6] A. Gounni, M. T. Mabrouk, M. El Wazna, A. Kheiri, M. El Alami, A. El Bouari, and O. Cherkaoui, “Thermal and economic evaluation of new insulation materials for building envelope based on textile waste,” Applied Thermal Engineering, vol. 149, pp. 475-483, 2019.

[7] C. A. Echeverria, W. Handoko, F. Pahlevani, and V. Sahajwalla, “Cascading use of textile waste for the advancement of fibre reinforced composites for building applications,” Journal of Cleaner Production, vol. 208, pp. 1524-1536, 2019.

[8] C. Stone et al., “Natural or synthetic–how global trends in textile usage threaten freshwater environments,” Science of the Total Environment, vol. 718, p. 134689, 2020.

[9] S. Palamutcu, “Electric energy consumption in the cotton textile processing stages,” Energy, vol. 35, no. 7, pp. 2945-2952, 2010.

[10] L. Grazzini, D. Acuti, and G. Aiello, “Solving the puzzle of sustainable fashion consumption: The role of consumers’ implicit attitudes and perceived warmth,” Journal of Cleaner Production, vol. 287, p. 125579, 2021.

[11] R. Piippo, K. Niinimäki, and M. Aakko, “Fit for the future: Garment quality and product lifetimes in a CE context,” Sustainability, vol. 14, no. 2, p. 726, 2022.

[12] World Commission on Environment and Development, “Our Common Future,” 1987. [Online]. Available: [URL needed].

[13] A. Shrivastava, G. Jain, S. S. Kamble, and A. Belhadi, “Sustainability through online renting clothing: Circular fashion fueled by Instagram micro-celebrities,” Journal of Cleaner Production, vol. 278, p. 123772, 2021.

[14] C. A. Echeverria, W. Handoko, F. Pahlevani, and V. Sahajwalla, “Cascading use of textile waste for the advancement of fibre reinforced composites for building applications,” Journal of Cleaner Production, vol. 208, pp. 1524-1536, 2019.

[15] United Nations, “Transforming our world: the 2030 Agenda for Sustainable Development,” 2015. [Online]. Available: [URL needed].

[16] J. Elkington, “Partnerships from cannibals with forks: The triple bottom line of 21st-century business,” Environmental Quality Management, vol. 8, no. 1, pp. 37-51, 1998.

[17] Textile Exchange, “Annual Report 2020,” 2020. [Online]. Available: https://textileexchange.org.

[18] B. Wanassi, A. Azzouz, and S. Gabbas, “Textile waste: A new frontier for industrial symbiosis,” Resources, Conservation and Recycling, vol. 164, p. 105190, 2021.

[19] P. Tanskanen and M. Hakanen, “The role of consumer behavior in sustainable clothing production,” Journal of Cleaner Production, vol. 141, pp. 152-160, 2017.

[20] Y. Wang and Y. Wang, “The impact of the COVID-19 pandemic on consumers' sustainable fashion consumption,” Journal of Fashion Marketing and Management, vol. 26, no. 1, pp. 88-104, 2022.

[21] M. Thomas, “Consumer awareness of sustainability in fashion: Challenges and opportunities,” Fashion and Sustainability, vol. 1, no. 2, pp. 150-164, 2020.

[22] M. Casado and A. Garcia, “Eco-labeling as a sustainable strategy in the fashion industry: Perspectives and trends,” Sustainability, vol. 14, no. 2, p. 726, 2022.

[23] S. Anton and J. Aldred, “Eco-labeling in fashion: Between greenwashing and genuine sustainability,” Journal of Fashion Marketing and Management, vol. 24, no. 2, pp. 231-247, 2020.

[24] International Organization for Standardization (ISO), “ISO 14001:2015 Environmental Management Systems,” 2015. [Online]. Available: [URL needed].

[25] World Economic Forum, “The State of Fashion 2021,” 2021. [Online]. Available: [URL needed].

[26] A. Kumar and R. Chandani, “Textile waste management in the textile and apparel industry: A review,” Waste Management, vol. 84, pp. 25-36, 2019.

[27] E. Turhan, “The role of waste management in sustainable development: An overview,” Waste Management, vol. 112, pp. 92-103, 2020.

[28] M. Ueda and H. Shimizu, “The life cycle of textile waste: An overview of global trends and challenges,” Waste Management, vol. 106, pp. 207-215, 2020.

[29] C. Stanciu and S. Mihaila, “The impact of textile waste on land degradation: A study of urban areas in Romania,” Land Degradation & Development, vol. 33, no. 2, pp. 234-245, 2022.

[30] World Resources Institute, “Fashion’s Environmental Impact: The Sustainable Fashion Initiative,” 2021. [Online]. Available: [URL needed].

[31] Ellen MacArthur Foundation, “A New Textiles Economy: Redesigning Fashion’s Future,” 2021. [Online]. Available: [URL needed].

[32] Ellen MacArthur Foundation, “A New Textiles Economy: Redesigning Fashion’s Future,” 2017. [Online]. Available: https://www.ellenmacarthurfoundation.org/assets/downloads/publications/A-New-Textiles-Economy-Report-2017.pdf.

Evaluating Consumer Perceptions and the Physical Performances of Recycled Textiles: Sri Lankan Apparel Consumers in Perspective

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***Abstract*— The World's textiles and clothing market has been growing steadily year on year for some time. The surge in clothing consumption has led to significant textile waste, with over 87% of discarded garments being deposited in landfills, more than 90% of which is either reusable or recyclable. Sri Lanka, being an apparel manufacturing hub, faces significant environmental concerns due to both consumer and industrial textile waste. Considering these aspects the study aims to examine the factors that cause consumer acceptance of recycled products and expand knowledge on the perceived barriers that stop them from buying recycled goods. The research utilizes a mixed-method approach, integrating consumer surveys with physical performance assessments of recycle and virgin materials. Physical testing was carried out to ensure that materials conformed to standards. The testing was conducted under ASTM standards, which included tensile strength, tear strength, and abrasion resistance. Test results demonstrate a slight difference between virgin and recycled fabrics. The survey which was carried out comprising 100 participants, indicated that participants' perception favored recycled fabrics in blind assessments; however, upon knowing about the recycled origin, their perception switched towards virgin fabrics, underscoring enduring prejudices about the quality of recycled textiles.**

This study emphasizes the necessity to enhance the physical characteristics of recycled fabrics and educate consumers regarding the environmental benefits and quality of recycled material. Addressing these problems is essential for improving customer acceptance and fostering sustainable practices in the fashion sector.

Keywords—recycled textiles, consumer perception, circular economy, sustainability, virgin cotton fabric

I. INTRODUCTION

The global demand for apparel has surged significantly in recent decades, leading to an unparalleled increase in textile waste. As consumer demand for apparel increases, so does the quantity of wasted clothing, a significant portion of which is deposited in landfills. Recent studies indicate that around 87% of abandoned textiles are directed to landfills worldwide, with over 90% of these materials being potentially reusable or recyclable [1]. This concerning number underscores the substantial environmental issues presented by the fashion and apparel sector, especially regarding waste management and sustainability. Thus, there is an increasing necessity to implement more sustainable methods within the sector to tackle these challenges. Furthermore, certain life styles in the world cause increase waste percentage. It is not only high consumption of T/C that generate waste but also products are over packaged. This way, it increases waste due to unnecessary packing material.

It is interesting to note that landfill is not keeping pace with the increase of waste in textiles. Its effect is that increase of cost in waste disposal. In today's context consumers discard large amount of textile waste (92 million tonnes per year). As cost of waste is increasing, more waste is getting recycled or reused. According to US Environmental Protection Agency (USEPA), the post-consumer recycled material is 15% annually. This would mean that 85% of waste will end up in landfilled [2].

In reaction to the waste dilemma, the concept of the circular economy has gained prominence, particularly in the textile and garment industries. A circular economy seeks to redefine growth by dissociating economic activities from resource use. It promotes the reuse and recycling of resources in order to reduce waste and lessen environmental impact [3]. Circular fashion, an aspect of this overarching economic strategy, aims to convert discarded textiles into new items. This transition signifies a shift from the conventional linear model of "take, make, waste," which has historically prevailed in the fashion business. The objective is to complete the cycle by ensuring that products are developed, manufactured, and utilized in a manner that prolongs their lifespan, reduces waste, and conserves resources [4]. In this context, textile recycling is essential for minimizing the environmental impact of fashion and for diverting a significant amount of waste from landfills [5]. This can be a daunting task.

The effective implementation of textile recycling as a solution to the environmental challenges of the fashion industry is significantly dependent upon customer acceptance and perception. Consumers are crucial in generating demand for sustainable products, and their perceptions of recycled textiles are vital for the efficacy of circular economy projects in the sector. A growing amount of research has concentrated on studying consumer attitudes and behaviors pertaining to recycled clothes products. Numerous factors, such as ecological awareness, brand reputation, product quality, and perceived value, have been recognized as the primary factors affecting consumer attitudes and purchase intentions [6].

Recent research indicates that customers' environmental awareness significantly influences their perceptions of recycled textiles. Researchers in China have discovered that aspects of perceived value and environmental awareness significantly influence consumers' attitudes towards recycled

clothing. Among these parameters, perceived quality value exerts the greatest significant influence on purchase intention, indicating that although consumers may favor sustainable products, they are acutely sensitive to the quality of those products [7]. A similar trend is evident in Turkey, where consumer values and environmental concerns substantially impact the purchasing intentions for garments composed of recycled materials [8]. These studies emphasize the increasing value of environmental considerations in consumer decision-making, indicating that customers are becoming more aware of the ecological consequences of their purchases.

Nonetheless, despite the evident environmental advantages of recycled textiles and the initiatives undertaken by brands to promote sustainability, customer perceptions of recycled items often constitute a challenge. Consumers typically show favorable attitudes towards recycled textiles; nonetheless, the general perception remains that these items are of poorer quality relative to those made from virgin materials and end up not purchasing them [9],[10].

Consequently, companies and brands have recognized the importance of reducing waste and have begun reintroducing the recycling of textile scraps. More sustainable manufacturing practices and increased recycling rates, coupled with consumer awareness, are essential components in promoting sustainable development and mitigating the environmental impact of the fashion and textile industry. Consumers are widely regarded as playing a crucial role in advancing sustainability efforts, as highlighted in initiatives like the EU Textile Strategy, where they are identified as one of the "12 key points for circular textiles." The dynamics of "globalization, consumerism, and recycling" and their impact on the clothing life cycle present various scenarios for addressing sustainability challenges [11].

Therefore, one approach to addressing the problem of textile waste is to implement the recycling of synthetic materials and to promote large-scale textile-to-textile recycling initiatives. Recycling textiles mitigates "environmental impacts," although varying scenarios yield differing degrees of environmental benefits. Compared to virgin textile fibers, the authors concluded that textile reuse and recycling offer significant environmental advantages by reducing the need for production—sustainable textiles are expected to be produced through environmentally friendly processes. High replacement rates are crucial for effective recycling, alongside short transport distances and extended usage phases for reuse. Additionally, recycling may involve non-textile materials and products [12].

The Sri Lankan apparel industry is a significant contributor to the country's economy, aiming for US$8 billion in annual revenue by 2025 [13]. However the apparel industry in Sri Lanka generated 28,745.3 tons of fabric waste in 2022, with 60% potentially recyclable and worth around USD 12.74[14]. As an apparel manufacturing hub, Sri Lanka faces significant environmental concerns due to post-industrial textile waste. Recent research indicates that a single manufacturing firm can produce 10 to 20 tons of post-industrial textile waste per month [15]. Considering the increasing demand for sustainable products and the continuous advancements in technology in recycled textile manufacturing, understanding Sri Lankan customer perceptions is crucial for promoting the wider acceptance of recycled textiles in the fashion sector. Therefore, it is of paramount importance to consumers to accept recycled textiles and efforts must be taken to change their perception towards recycled textiles to overcome environmental challenge.

Recent advancements in recycling technologies may close the perceived quality disparity between recycled and virgin fabrics. Nonetheless, without a comprehensive comprehension of customer sentiments, these technological innovations may fail to achieve broad commercial acceptability. This study investigates customer perceptions of recycled cotton fabric to determine if negative views on the quality and durability of recycled textiles are justified.

This study employs a mixed-method approach: it investigates consumer views of textiles made of virgin material versus recycled cotton through a survey, specifically aiming to uncover the attitudes regarding the use of recycled materials in clothing. Second, the study performs three essential physical tests—tearing strength, tensile strength, and abrasion resistance—to evaluate the performance of recycled materials in comparison to virgin fabrics. This research seeks to evaluate consumer perceptions and the physical characteristics of recycled textiles to offer a comprehensive perspective on the viability of recycled materials in the fashion industry, thereby facilitating the sector's shift towards more sustainable and circular production models.

II. Methodolgy

A. Fabric Selection

This study employed two types of commonly used cotton fabrics: denim (twill weave) and plain weave. Recycled and virgin materials were sourced for each fabric type to facilitate a balanced comparison. According to the recent research, Mechanical recycling of post-consumer cotton waste may produce yarns and textiles for high-value products, even with potential compromises in fiber quality [16]. Therefore, 100% cotton woven fabrics were chosen and those fabrics were chosen to be similar in weight, weave type, and fiber composition, ensuring the comparability of their physical characteristics. By controlling these variables, the study aimed to provide an impartial evaluation of the differences in performance between recycled and virgin fabrics.

The recycled fabric samples labeled as Denim R and Plain weave R, and the virgin fabric samples labeled as Denim V and Plain weave V. Detailed specifications for the fabrics are provided in the table below.

TABLE 1 FABRIC SELECTION

Sample Name	Fabric Content	Fabric Weight (g/m^2)	Fabric Construction (Warp dencity)	Fabric Weave Type
Denim R	100% cotton	288	84	2/1 'z' twill
Denim V	100% cotton	263	72	2/1 'z' twill
Plain weave R	100% cotton	144	118	Plain weave
Plain weave V	100% cotton	135	124	Plain weave

B. Consumer Survey

A consumer survey was conducted to evaluate perceptions of recycled compared to virgin fabrics. The survey involved

two separate cohorts: 55 random consumers who had purchased apparel products from four different retailers in the Western province of Sri Lanka, and 45 individuals employed at apparel manufacturing facilities in Sri Lanka. The survey methods employed were subjective and aimed to assess consumer preferences and perceptions across different scenarios. Three unique methodologies were employed to collect this information.

- Method 1- Blind fabric selection by hand feel (Pillory Box). Participants were instructed to choose fabrics from a pillory box without any prior knowledge of the fabric types. The sole assessment criterion was the "hand feel" of the materials, enabling participants to form an unbiased opinion based purely on tactile experience.
- Method 2- Visual and tactile preference without knowledge of fabric type. In this, the participants were presented with both recycled and virgin materials without disclosure of their source material. They were subsequently requested to assess and choose the fabric they favored based on both aesthetics and tactile sensation. This study aimed to evaluate if consumers' aesthetic and tactile preferences corresponded with their quality assessments, regardless of the fabric's recycled or virgin classification.
- Method 3- Informed Feedback on Fabric Type. In this method, the participants were explicitly informed regarding which fabric was recycled and which was virgin. Participants were subsequently requested to offer input on their choices, taking this information into account. This method was developed to examine whether the understanding of the fabric's origin may affect consumer attitudes and preferences, especially with their tendency to select recycled materials.

C. *Fabric Property Tests*

In addition to the customer survey, three physical tests were conducted to evaluate the performance of recycled and virgin fabrics. Each test was conducted in accordance with American Society for Testing and Materials (ASTM) standards. The subsequent tests were selected for their pertinence to the longevity and quality of fabrics used in apparel manufacturing:

Tensile Strength Test –The tensile strength testing method (ASTM D5034) utilizes a tensile testing machine equipped with a 50 kg load cell and a traverse rate of 100 mm/min. Samples were prepared (dry and wet), secured in pneumatic jaws, and subjected to tension until the fabric breaks. The load required (kg) for breakage is measured to determine tensile strength. This test is used to measure the fabric's strength when subjected to tension, providing insights into its durability and elasticity.

Tear Strength Test – The tear strength test is used to evaluate the force required to tear the fabrics, providing a measure of their resistance to tearing. This test (ASTM D2261) uses an Elmendorf tear tester to assess fabric resistance to tearing. Specimens (80mm x 58mm) are clamped, and a 15mm cut is made. The pendulum is released, and the force required to tear the fabric is recorded. The test is repeated for four additional specimens of the same fabric to ensure accuracy.

Abrasion Resistance Test – This test (ASTM D4966) assesses the durability of the fabrics by subjecting them to repeated friction. Martindale Abrasion Machine is used to evaluate the resistance of fabric and durability. Four circular fabric specimens (38mm) are positioned in holders with polyether foam and felt layers. Upon attaching the holders and affixing weights, the machine runs for 5,000 revolutions. Fabric wear is examined, and testing persists until observable damage occurs or a certain threshold is attained.

D. *Data Analysis*

The data obtained from customer surveys and physical fabric tests were carefully analyzed and displayed using tables and charts, enabling a clear comparison of consumer preferences among the three survey methodologies. These visual instruments facilitated the identification of trends in consumer behavior, including preferences for recycled vs. virgin fabrics based on tactile sensation, aesthetics, and awareness of the fabric's provenance.

The physical test findings were examined using comparative tables and charts to emphasize the disparities in tensile strength, tearing strength, and abrasion resistance between recycled and virgin fabrics. The analysis aimed to visually presents the test results to determine whether recycled fabric performance is comparable to virgin fabrics in key performance areas.

III. Results and Discussion

A. *Consumer Survey*

The consumer survey, executed using three different methodologies, provided significant insights into consumer perceptions towards recycled fabrics. Fig. 1 presents a summary of the survey.

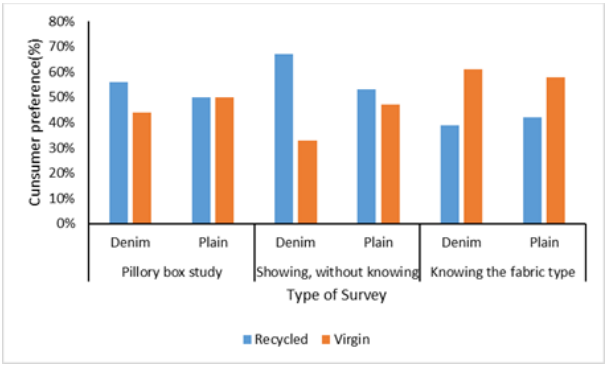

Fig.1 Consumer preference towards recycled fabrics

In Method 1, participants chose materials solely based on tactile feeling, unaware of the fabric type, resulting in a greater preference for recycled denim (56%) compared to virgin denim (44%). Preferences for plain weave were evenly divided between recycled and virgin materials, each accounting for 50%. The findings indicate that when consumers lack knowledge of a fabric's origin, recycled materials might exhibit favorable tactile qualities.

In Method 2, participants were provided with both fabric types without being informed of their recycled or virgin status, and the results again favored recycled materials. A majority of participants (67%) expressed a preference for recycled denim, while 53% favored the recycled plain weave fabric. This suggests that in the absence of preexisting preferences against

recycled materials, customers often choose recycled fabrics solely based on their aesthetic and tactile qualities.

The study demonstrates that when consumers are unaware of a fabric's origin (Method 1 and Method 2), recycled fabrics—specifically recycled denim and plain weave—are often preferred. These results indicate that recycled fabrics possess desirable tactile qualities that compete well with virgin materials, suggesting that recycled textiles are not inherently inferior in terms of feel or appearance. This is a positive outcome for sustainable materials, as it shows that recycled fabrics can perform well in sensory-based evaluations, which may play a crucial role in driving consumer adoption of more sustainable options in the absence of preconceived biases.

In Method 3, when participants were clearly informed about the fabric type, consumer preferences significantly shifted towards virgin materials. In this study, 61% of individuals favored virgin denim, whereas 58% selected virgin plain weave materials. This transition indicates that although recycled fabrics could perform well in blind assessments, consumer opinions are significantly affected by the awareness that a fabric is recycled. A significant number of consumers equate recycled materials with lower quality, perhaps preventing them from selecting these fabrics upon recognizing their source. This notable change reveals a significant psychological bias against recycled fabrics, which appears to override the sensory experience. The fact that consumers switched to favor virgin fabrics after learning their origin suggests that many consumers still associate recycled materials with lower quality, durability, or status.

This shift reflects a critical challenge in the sustainable fashion industry—perceptions of quality and value based on material origin. Even when the tactile qualities of recycled fabrics are deemed favorable, preconceived notions about recycled products being inferior can negatively impact consumer choices. This demonstrates that consumer education and awareness are critical in shifting these biases and fostering a more positive perception of recycled materials.

According to a study done in Bangladesh, Consumers aged 25 to 45, belonging to higher social strata and possessing advanced educational backgrounds, are increasingly more aware of and interested in sustainability compared to children under 15 and older individuals over 45[17]. It reveals that demographic factors such as gender, age, socioeconomic status, and educational background play a crucial role in shaping consumer expectations.

Other studies [18],[19], which presented sustainability concepts and explored how fashion retailers address sustainability, revealed that their understanding of fashion sustainability was limited despite participants engaging in some sustainable practices. The present study shows the importance of raising awareness of sustainability among textile consumers. Awareness has the potential to impact sustainable fashion behaviors and consumption patterns positively. Many studies acknowledged a rising awareness of sustainability in general, the growing popularity of trends like the sharing economy through collaborative consumption, and an increasing recognition among fashion industry companies of the need to offer sustainable products [20].

However, the contrast between blind preferences and informed choices underscores a key insight: the actual tactile and aesthetic qualities of recycled fabrics may meet or even exceed consumer expectations, but these advantages are overshadowed by the stigma attached to recycled products. The results suggest that while sustainable materials have made strides in quality, the success of these materials in the marketplace hinges on overcoming negative consumer perceptions. To address this bias, there is a clear opportunity for targeted consumer education and marketing strategies that emphasize the benefits of recycled materials, such as environmental impact, innovation in recycling technology, and the improved quality of modern recycled fabrics. Fashion brands and retailers could benefit from more transparent communication about the sustainability and performance of recycled fabrics to challenge preconceived notions and encourage more eco-conscious purchasing behaviors. While the study provides valuable insights, it would benefit from exploring why consumers perceive recycled fabrics as inferior. Additionally, testing a broader range of fabrics and demographic segments may yield more generalized conclusions.

B. Tensile Strength

The tensile strength test findings indicated a noticeable distinction in the performance of virgin and recycled fabrics in both Denim and Plain weave samples, as illustrated in Fig. 2.

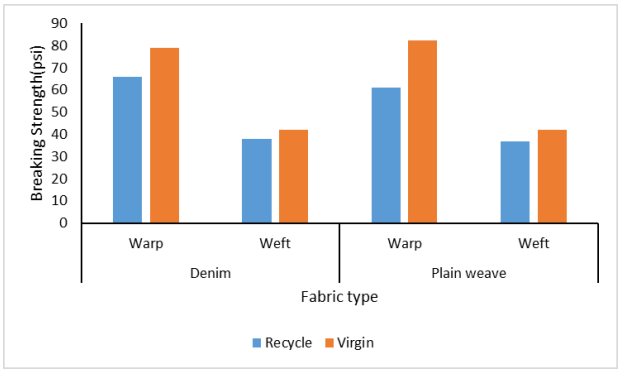

Fig.2. Tensile Strength of Recycled and Virgin Fabrics

Virgin fabrics had greater tensile strength than their recycled equivalents. The tensile strength in the warp direction for Denim Virgin (78.8 Nm) exceeded that of Denim Recycled (66 Nm), and the difference in the weft direction was equally significant, with Virgin at 42.2 Nm and Recycled at 37.9 Nm. Comparable trends were noted in Plain weave textiles, wherein Virgin samples had markedly superior tensile strength in both warp (82.2 Nm) and weft orientations (42.2 Nm), relative to the Recycled fabrics (61.2 Nm and 36.8 Nm), respectively.

The difference indicates that the recycling process could reduce the tensile strength of fabrics, possibly due to the degradation of fibers during recycling. Virgin fibers, being unprocessed and maintaining their complete structural integrity, generally demonstrate superior durability. The reduced tensile strength of recycled fabrics may affect their long-term usability, especially in goods requiring significant resilience. The degradation makes recycled materials less durable and potentially less suitable for applications requiring high strength and resilience. This finding is significant because it underscores a tangible quality difference between virgin and recycled fabrics, with virgin materials demonstrating superior strength and long-term durability.

C. Tear Strength

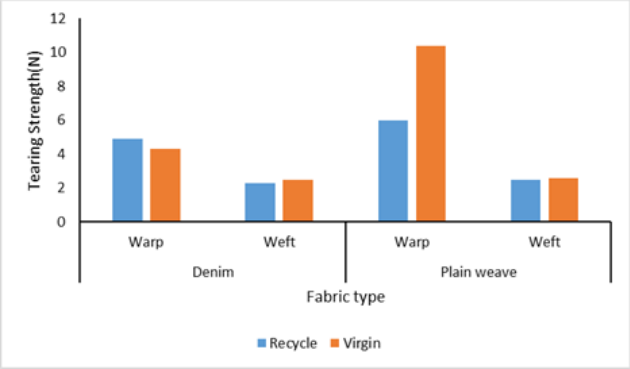

Fig.3. Tear Strength of Recycled and Virgin Fabrics

In Denim, there was no notable distinction between the recycled and virgin materials in the warp and weft directions, with Denim Recycled (4.9 N and 2.3 N) showing comparable performance to Denim Virgin (4.3 N and 2.5 N). In Plain weave textiles, Virgin samples exhibited significantly higher tear strength in the warp direction (10.4 N) relative to the Recycled samples (6 N). The tendency was not as noticeable in the weft direction, with a small change (Virgin: 2.6 N, Recycled: 2.5 N).

The variation in tear strength, particularly in Plain weave fabrics, emphasizes the importance of fabric structure and fiber integrity in determining fabric performance. The recycling process may affect the fiber's ability to endure tearing forces, especially in more delicate or loosely woven structures such as Plain weave. This could be a limiting factor for recycled fabrics in applications requiring high tear resistance. This result suggests that fabric structure plays a critical role in determining tear strength, with plain weave being more vulnerable to recycling impacts than the more robust denim structure. The lower tear strength in recycled plain weave fabrics indicates that these materials may be less appropriate for high-stress applications. The recycling process, which degrades fibers, may impair the fabric's ability to withstand tearing forces, especially in looser weaves like plain weave, where the structural integrity is already less robust.

D. Abrasion Resistance

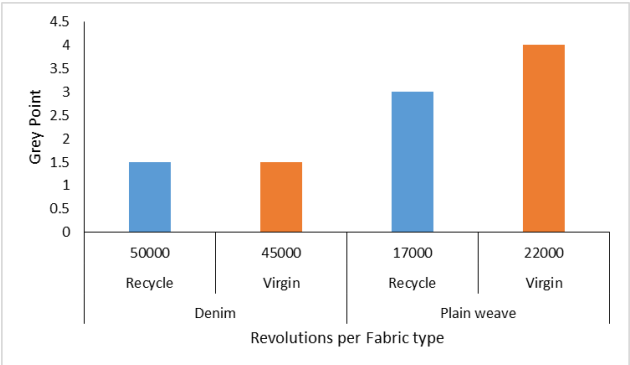

Fig. 4. Abrasion Resistance of Recycled and Virgin Fabrics

In the case of Denim, both the Recycled and Virgin samples exhibited comparable performance, achieving a grey scale rating of 4 following 50,000 abrasion cycles. This indicates that recycled denim materials exhibit friction and wear resistance comparable to virgin fabrics, rendering them a suitable choice for applications necessitating resilience against abrasion. The recycled denim is highly comparable to virgin denim in terms of friction and wear resistance, making it a viable alternative for applications requiring strong abrasion resistance. However, in plain weave fabrics, virgin materials significantly outperformed recycled ones.

Nevertheless, a significant distinction was noted in Plain weave materials. Virgin materials had superior abrasion resistance, achieving a grey scale rating of 4 after 22,000 cycles, whereas recycled fabrics received a grade of 3 after 17,000 cycles. The diminished abrasion resistance of recycled plain weave fabrics indicates they could degrade more rapidly under continuous contact, rendering them less appropriate for high-wear applications. The recycling procedure probably impacts the fiber structure, reducing its durability against wear over time.

The laboratory findings present a sharp contrast to the consumer perception results from the earlier study, where participants in blind tests often favored recycled fabrics based on tactile qualities. In Methods 1 and 2 of the consumer study, recycled materials were preferred over virgin materials (e.g., 67% preferred recycled denim), indicating that consumers perceive recycled fabrics positively in terms of touch and feel. However, once participants were informed of the fabric's origin, the preference shifted significantly toward virgin materials, with 61% favoring virgin denim.

The laboratory results confirm that this shift in preference might be justified by objective performance metrics. Virgin fabrics consistently exhibited higher tensile strength, better tear resistance (especially in plain weave fabrics), and superior abrasion resistance in certain cases. Consumers' initial positive tactile response to recycled fabrics may not align with the materials' actual long-term performance, particularly when considering applications that require high strength or durability. Once aware of the fabric's recycled origin, consumers might assume lower quality—an assumption corroborated by the laboratory findings, especially regarding tensile strength and wear resistance.

The laboratory analysis suggests that consumer perceptions of recycled fabrics being of lower quality may have some basis in reality, particularly in terms of tensile strength and long-term durability. While consumers may appreciate the tactile qualities of recycled materials in blind assessments, their concerns about the potential for inferior performance are supported by the objective data. This gap between initial perception and actual performance emphasizes the need for education and communication about the strengths and limitations of recycled fabrics.

To positively influence consumer perception, companies in the fashion industry may need to invest in improving the quality of recycled fabrics—especially their tensile and tear strength—through better recycling processes that minimize fiber degradation. Alternatively, brands could focus on promoting recycled fabrics for applications where wear resistance, rather than tensile strength, is the primary concern (e.g., denim). Moreover, transparency around how recycled materials are tested and their limitations could help manage consumer expectations, fostering more informed purchasing decisions.

IV. Conclusion

This study emphasizes the differences in physical characteristics between recycled and virgin materials, combined with customer opinions regarding recycled textiles. Virgin materials demonstrated higher tensile strength, tear strength, and abrasion resistance, particularly in Plain weave samples, however recycled fabrics, notably Denim, showed comparable performance in certain aspects. Consumer surveys indicated that, in blind assessments, individuals often chose recycled fabrics, implying that recycled materials may compete with virgin textiles in feel and visual appeal. Nevertheless, when participants were made aware of the fabric's recycled origin, their preferences moved towards virgin fibers, indicating enduring misconceptions regarding the quality of recycled materials.

Enhancing the physical performance of recycled textiles and educating consumers about their environmental advantages and equivalent quality is essential for promoting growing acceptance of these fabrics. Improving consumer knowledge and bridging perception gaps will be crucial for encouraging more widespread adoption of sustainable practices in the fashion and apparel sector.

The disparity between consumer perception and laboratory results underscores the need for clearer communication and improvement in recycled fabric technology. While recycled fabrics can be competitive in specific areas like abrasion resistance for denim, their performance in tensile strength and tear resistance remains a challenge. Addressing these technical limitations and educating consumers about the durability of recycled fabrics in appropriate contexts can help close the perception gap and encourage more widespread acceptance of sustainable materials

References

[1] S. Moazzem, E. Crossin, F. Daver, and L. Wang, "Environmental impact of apparel supply chain and textile products," Environment Development and Sustainability, vol. 24, no. 8, pp. 9757–9775, Oct. 2021, doi: 10.1007/s10668-021-01873-4.

[2] J. J. Lu and H. Hamouda, "Current Status of Fiber Waste Recycling and its Future," Advanced Materials Research, vol. 878, pp. 122–131, Jan. 2014, doi: 10.4028/www.scientific.net/amr.878.122.

[3] F. Jia, S. Yin, L. Chen, and X. Chen, "The circular economy in the textile and apparel industry: A systematic literature review," Journal of Cleaner Production, vol. 259, p. 120728, Feb. 2020, doi: 10.1016/j.jclepro.2020.120728.

[4] R. Rathinamoorthy, "Circular fashion," in Elsevier eBooks, 2018, pp. 13–48. doi: 10.1016/b978-0-08-102630-4.00002-9.

[5] S. Abrishami, A. Shirali, N. Sharples, G. E. Kartal, L. Macintyre, and O. Doustdar, "Textile Recycling and Recovery: An Eco-friendly Perspective on Textile and Garment Industries Challenges," Textile Research Journal, May 2024, doi: 10.1177/00405175241247806.

[6] X. Tong and J. Su, "Factors Affecting Consumers' Perceptions and Behaviors toward Apparel Products Made of Recycled Materials," Innovate to Elevate, Dec. 2022, doi: 10.31274/itaa.15795.

[7] X. Jin, A. Omar, and K. Fu, "Factors Influencing Purchase Intention toward Recycled Apparel: Evidence from China," Sustainability, vol. 16, no. 9, p. 3633, Apr. 2024, doi: 10.3390/su16093633.

[8] T. Şener, F. Bişkin, and N. Dündar, "The effects of perceived value, environmental concern and attitude on recycled fashion consumption," Journal of Fashion Marketing and Management, vol. 27, no. 4, pp. 595–611, Aug. 2022, doi: 10.1108/jfmm-01-2021-0003.

[9] A. Polyportis, R. Mugge, and L. Magnier, "Consumer acceptance of products made from recycled materials: A scoping review," Resources Conservation and Recycling, vol. 186, p. 106533, Jul. 2022, doi: 10.1016/j.resconrec.2022.106533.

[10] M. M. Wagner and T. Heinzel, "Human Perceptions of Recycled Textiles and Circular Fashion: A Systematic Literature Review," Sustainability, vol. 12, no. 24, p. 10599, Dec. 2020, doi: 10.3390/su122410599.

[11] M. M. Wagner and T. Heinzel, "Human Perceptions of Recycled Textiles and Circular Fashion: A Systematic Literature Review," Sustainability, vol. 12, no. 24, p. 10599, Dec. 2020, doi: 10.3390/su122410599.

[12] G. Sandin and G. M. Peters, "Environmental impact of textile reuse and recycling – A review," Journal of Cleaner Production, vol. 184, pp. 353–365, Feb. 2018, doi: 10.1016/j.jclepro.2018.02.266.

[13] N. Weerasinghe, A. Weerasinghe, Y. Perera, S. Tennakoon, N. Rathnayake, and P. Jayasinghe, "Sustainability practices and organizational performance during the COVID-19 pandemic and economic crisis: A case of apparel and textile industry in Sri Lanka," PLoS ONE, vol. 18, no. 7, p. e0288179, Jul. 2023, doi: 10.1371/journal.pone.0288179.

[14] L. M. Edirisinghe, A. Alwis, and M. Wijayasundara, "Uncovering the circular economy potential of industrial waste in Sri Lanka (case study from textile industrial - fabric waste)," E3S Web of Conferences, vol. 436, p. 08012, Jan. 2023, doi: 10.1051/e3sconf/202343608012.

[15] D. G. K. Dissanayake and D. Weerasinghe, "Managing post-industrial textile waste: current status and prospects for Sri Lanka," Journal of the Textile Institute, vol. 112, no. 11, pp. 1804–1810, Nov. 2020, doi: 10.1080/00405000.2020.1845461

[16] H. Cao, K. Cobb, M. Yatvitskiy, M. Wolfe, and H. Shen, "Textile and Product Development from End-of-Use Cotton Apparel: A Study to Reclaim Value from Waste," Sustainability, vol. 14, no. 14, p. 8553, Jul. 2022, doi: 10.3390/su14148553.

[17] A. D. Pranta, Md. T. Rahaman, Md. R. Repon, and A. A. R. Shikder, "Environmentally sustainable apparel merchandising of recycled cotton-polyester blended garments: Analysis of consumer preferences and purchasing behaviors," Journal of Open Innovation Technology Market and Complexity, vol. 10, no. 3, p. 100357, Aug. 2024, doi: 10.1016/j.joitmc.2024.100357.

[18] E. L. Ritch, "Experiencing fashion: the interplay between consumer value and sustainability," Qualitative Market Research an International Journal, vol. 23, no. 2, pp. 265–285, May 2020, doi: 10.1108/qmr-09-2019-0113.

[19] M. Wiederhold and L. F. Martinez, "Ethical consumer behaviour in Germany: The attitude‐behaviour gap in the green apparel industry," International Journal of Consumer Studies, vol. 42, no. 4, pp. 419‐429, Mar. 2018, doi: 10.1111/ijcs.12435.

[20] M. M. Wagner and T. Heinzel, "Human Perceptions of Recycled Textiles and Circular Fashion: A Systematic Literature Review," Sustainability, vol. 12, no. 24, p. 10599, Dec. 2020, doi: 10.3390/su122410599.

Reducing Cycle Time of Raw Material Sourcing for Accelerated Supply Chains in Sri Lankan Apparel Industry.

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***Abstract*— Reducing cycle time of raw material sourcing is essential in the fast-paced and highly competitive garment sector to achieve operational excellence by accelerating supply chain operations and satisfy changing consumer demands. Reduction in failures of order fulfilment in full and precise utilization of excess capacity to cater new orders are key determinants of success in dynamic apparel industry in Sri Lanka. This study investigates methods for streamlining the sourcing of raw materials in the context of the Sri Lankan garment sector with expectation of achievement of accelerated supply chains. To fully identify the various aspects impact on cycle time of raw material sourcing, the study uses qualitative research techniques combining with multiple data visualizing and analytical tools. Questionnaires and in-depth interviews with industry participants such as apparel manufacturers, raw material suppliers and logistics specialists are parts of qualitative research tools. The study also identifies inefficiencies in raw material sourcing which hinder operational efficiencies in supply chain and examines cutting-edge tools and techniques to minimize the cycle time in raw material sourcing using advanced digital technology, automation, supplier diversity and supplier management, sustainable practices, lean concepts and strategic inventory management, vertical integration. Furthermore, recommendations to reduce cycle time of raw material sourcing are provided to achieve ultimate outcome of accelerated supply chains in apparel industry in Sri Lanka.**

Keywords—Cycle time, Raw material sourcing, Supply chain, Apparel Industry, Supplier management

I. INTRODUCTION

The global apparel industry provides a significant contribution to world economy, particularly for developing and least developed countries where apparel becomes a substantial share of total exports despite of the very dynamic nature of the industry [1]. With the changes in technology highlighting digital transformation and the growing competition in the challenging business environment, apparel companies have realized they have to face the challenges strategically and deploy new initiatives and approaches ensuring flexibility, agility and operational resilience [2].

When considering Sri Lankan textile and apparel industry, it took off immediately when the economy was liberalized and, at present, it is the highest export revenue generating source to the country and the industry which provides a greater number of employments [3]. Also, Sri Lanka is known as a world class apparel manufacturer serving for multiples of globally established brands. Currently, there are around 300 apparel manufacturers and exporters in Sri Lanka in large, medium and small scale [4].

Apparel product categories produced in Sri Lanka are extensive and examples are sportswear, lingerie, loungewear, swimwear, workwear, etc. The label "Made in Sri Lanka" provide a unique identity for the apparel products manufactured in Sri Lanka in terms of quality, reliability and best practice related to sustainability, environment, social responsibility and ethics.

The sustainable survival and growth of the recent apparel industry is predominantly depending on the balance among economic, environmental and social considerations fueled by sustainability practices, agile, flexible and accelerated supply chain management, innovation and technology, adaptability of market, consumer behaviour and preferences, brand reputation and circular economy [5]. In context of supply chain management in apparel industry, supply chain excellence, optimization and integration have emerged as critical goals.

The main raw materials in the apparel industry includes fabric and laces which is significantly time consuming to produce and accessories such as labels, buttons, and packaging materials. The cycle time of sourcing of these raw materials encompasses the duration from placing an order to receiving the goods, incorporating various stages, preprocessing, processing and post processing. The effective and efficient management of operations related to upstream and downstream is mandatory to ensure accelerated supply chain within an apparel manufacturing organization in which raw material sourcing is the key function of upstream operations.

However, apparel manufacturers are struggling to achieve timely sourcing of raw materials while maintaining the necessary quality and quantity. This challenge hinders their ability to remain competitive in a dynamic business environment. Contributing factors include inflexible and ineffective processes, outdated systems that fail to adapt to rapid market changes, organizational culture and resistance to change, communication gaps, legal and compliance concerns, and fluctuating costs [6]

With that note, it is vital to understand exact hinderances which increase the cycle time of raw material sourcing and take actions to rectify the identified obstacles with aid of technology and supporting supply management techniques to ensure the accomplishment of advanced, flexible and accelerated supply chains within the apparel industry.

II. Literature Review

Sri Lanka started producing "ready-to-wear" garments during 1960-1970 and the Sri Lankan apparel sector expanded notably following the economic liberalization in 1977 gaining the advantage of "quota-hopping" [7]. In current scenario, the apparel industry in Sri Lanka heavily depends on the imported raw materials such as fabric and accessories (80%-90% fabrics and 70%-90% accessories) leading to high negative impacts on production speed and cycle time if delays and inefficiencies occur in upstream process [6].

A. Supply chain management

Supply chain management is a critical business aspect focusing on coordination of activities related to planning and design, strategic sourcing, supply management and production, logistic integration and distribution, supply network coordination, marketing and sales [8],[9]. Therefore, it can be elaborated that the supply chain management is a seamless process connecting all the parties in the chain including departments within an organization, suppliers, customers, third party companies and information system providers [10]. Furthermore, supply chain networks can be categorized into two; producer driven supply chains such as automobile, aircrafts, computers, heavy machinery, etc. which is common in capital and technology intensive industries and buyer driven supply chains such as clothing, footwear, toys, office supplies, etc. which is common in labor intensive industries [11]. As Manjumder and Srinvasan [12] highlighted large interconnected and decentralized supply networks are common in auto-mobile and apparel industries. Currently, these types of industries have a high tendency of shifting towards concept of lean and related philosophy which lead to heighten the interdependency among nodes in the supply chain.

B. Raw Material Sourcing

Having an effective raw material sourcing operation is critical for any business organization considering the importance to create strong and well-defined policies on supplier relationships, sourcing and communication which are considered as key elements in supply chain management [8]. Different companies are having their own raw material sourcing strategies according to their business model and culture. Some companies practice a hand-off strategy in managing its raw materials, when others follow interactive relationships with suppliers in order to have cost reductions, quality improvements, advantages over delivery time, dissemination of information on market demand, production schedules and creations of avenues to new productions [13].

However, with the increasing trends in globalization and global business strategies adopted, it becomes mandatory to company to go ahead with global sourcing [14]. The global sourcing is involved in integration and coordination of sourcing requirements across worldwide business unit and examination, creation and development of common items, processes, technologies and suppliers which are appropriate and can easily access regardless of the locations or other boundaries [15]. Global sourcing structures and processes including logistics and supply chain processes and information systems, employees' skills and top management commitment are crucial factors which determines the company's global sourcing business capabilities and its effectiveness [16].

There are five stages in general global sourcing process. In first stage of investigation and tendering stage is where the core activities of the sourcing process identified along with an analysis of company, customer and competitors, In the second stage sourcing strategy is started to formulate. In the third stage, the supplier selection criteria are defined, prescreening is carried out and economic and operating benefits are estimated. The supplier selection and development are related to activities of negotiation, technical assessment, saving identification and implementation of schedules. The fourth stage is related to team strategy and schedule, agreements on supply and logistic terms, measurement of actual performance and progress report. Final stage is performance measurement and continuous improvement in which monitoring of supplier performance, relationship analysis, continuous improvement opportunities and maintaining of a dynamic and flexible procurement process will be the main aspects [17].

Stock & Lambert [18] pointed out that there is a rise of concepts in low buffer stock and make-to-order strategies with the embrace of lean supply chain which can lead to a greater risk of stock outs and other deficient service performance in upstream of supply chain which can propagate negative impacts throughout the downstream of supply chain and adversely affected on the customer expectations and company performances. Low Buffer Stock minimizes inventory with demand forecasting for cost efficiency, while Make-to-Order produces items post-order to avoid excess stock. Therefore, it is a crucial factor having greater levels of trust, strong and loyal relationship with key suppliers and exploration of opportunities for colocation and effective information sharing lead to rectification of raw materials sourcing inefficiencies and uncertainties and ultimately increasing in the responsiveness of overall supply chain [19].

Apart from that the firms vertically integrate because of asset specificity of the resources of the suppliers in backward or lead firms in the forward linkages. The level to which firm owns its upstream suppliers and its downstream buyers is referred to as vertical integration. This gives the manufacturing company both cost advantages, controlling power and flexibility [20]. Furthermore, maintaining effective communication channels among suppliers and customers are extremely important because it ensures timely, coordinated receipt of information by all relevant parties. For example, when there is a transport issue with the delivery and if that issue is quickly escalated to relevant parties, it would be able to solve the problem together by identifying other possible carriers and devising alternate strategies, to avoid customer outrage or a supplier shutdown [21].

The impact of supplier quality on organization's performance is immense and direct and understanding the quality of inputs is equally important as understanding the quality of outputs [22]. When there is a supplier failure, it is important to analyze and understand how manufacturers reacts because these reaction costs would be significant for both suppliers and manufacturers. Therefore, supplier quality management is a potential set of activities initiated by the manufacturer including tracking the cost of supplier quality, implementation of performance-based supplier score cards and conducting audits in order to improve lead time on raw material sourcing and achieve customer satisfaction [23].

C. Potential for new technology

Modern information management and product development have been transformed dramatically to different horizons with the development of industry 4.0. applications such as Internet of Things (IoT), big data, cloud computing (CC), Cyber Physical System (CPS) and additive manufacturing [24]. Business models, production systems, machines, product and services, employees and environment are digitalized with the light of Industry 4.0 using specialized tools across design, production, and supply chain management, such as CLO 3D and Adobe Illustrator for design, SAP for enterprise management, and Blue Yonder for supply chain optimization. Technologies like RFID for inventory tracking, Higg Index for sustainability assessment, and PLM software such as Centric PLM. All can be interconnected on a digital platform with a respective virtual configuration enabling fast and information flow in order to real-time engagement of all the elements in the value chain. [25]. For example, the fast fashion brands like Zara have implemented digital supply chain management to ensure quick responses to trends and consumer preferences. [26]. Besides, digital platforms improve the inter-functional coordination within the organization facilitating seamless communication and information sharing across departments [27].

III. Methodology

A. Research Design

The study employed a qualitative research method to collect data for the research. The existing knowledge required to proceed the research was acquired through sources presented by other researches and to generate new knowledge the required data are obtained through a comprehensive questionnaires and interviews. The key considerations are factors impacting on cycle time increase in raw material sourcing in apparel industry and how cycle time of raw materials sourcing can be reduced through various management techniques such as lean concept, vertical integration, forecasting techniques , inventory management systems and introduction of new technology.

B. Participants:

The participants are executive level and above employees of Sri Lankan Apparel Industry. The analyse was conducted based on one hundred and sixty five questionnaire responses and ten in-depth interviews with representatives of five apparel manufacturing organizations involving in sourcing and supply chain section and product control unit. To ensure the data validity, it was only considered responses from employees who worked at least one year.

C. Instruments

The questionnaire used for the survey consists of eleven questions covering main challenges related to cycle time of raw material sourcing and innovative strategies and technologies for enhance raw material sourcing. The questionnaire is a mix of multiple choice, open end, demographic and closed-ended questions. The structured interview comprises of open-end questions by giving the interviewees freedom to present their ideas and insights without any barriers.

D. Procedures:

The questionnaires of surveys were conducted online by sharing a google form among possible candidates through human resource department of apparel maufacturing companies considered. The interviews were conducted as online sessions and in-person sessions.

E. Data Analysis:

The data collected from survey questionnaire and the in-depth interviews were arranged in structured formats such as spreadsheets in order to ensure the ease of data analysis. The data were then organized according to the research objectives, and analysis was conducted using a content analysis approach. Pie charts and tables were mainly used for data presentations.

IV. Results

Eleven challenges in raw material sourcing have been questioned; namely limited supplier network and supplier reliability, transportation delays, seasonal variations, quality control issues, communication issues, Cycle time variability and cycle time visibility, inefficiencies in inventory management and supply chain disruptions, cost fluctuations, compliance and regulations, nonavailability of forecast or projections and other. Some challenges identified are completely external obstacles such as seasonal variations and cost fluctuation which cannot be controlled by apparel manufacturer.

Figure 1 demonstrates summary of responses received through questionnaire in relations to main challenges for cycle time of raw material sourcing. According to the table 1, the five main challenges for raw material sourcing are transportation delays (16%), quality control issues (16%) , cost fluctuations (15%), seasonal variations (14%) and communication issues (14%).

TABLE 1: PERCENTAGE OF RESPONSES FOR CHALLENGES FOR RAW MATERIAL SOURCING

Challenge	Frequency	Percentage
Limited Supplier Network & Supplier Reliability	55	8
Transportation Delays	111	16
Seasonal Variation	92	14
Quality control issues	111	16
Communication issues	93	14
Cycle Time Variability & Visibility	37	5
Inventory Management & Supply Chain Disruptions	34	5
Cost fluctuation	102	15
Compliance and Regulations	27	4
Non availability of forecast/ Projection	19	3

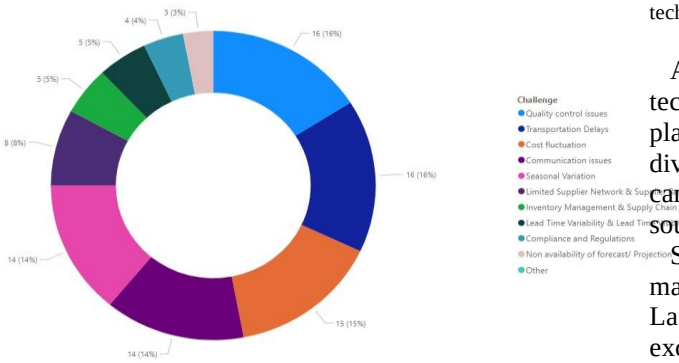

Fig.1. Challenges for raw material sourcing.

The ability to use new technology and lean concepts along with supply chain management tools to reduce cycle time of raw material sourcing in Sri Lankan apparel industry have been analysed under eleven possibilities. They are advanced forecasting and demand planning, digital supply chain platforms, radio frequency identification (RFID) and internet of thing (IoT) tracking, lean manufacturing, supplier diversification, data analytics and artificial intelligence (AI), vertical integration, e-commerce and online marketplaces, block chain technology, automated order processing, sustainable and eco- friendly practices and others.

TABLE 2: PERCENTAGE OF POTENTIAL TO USE TECHNOLOGY AND MANAGEMENT TECHNIQUES TO REDUCE CYCLE TIME OF RAW MATERIAL SOURCING.

Description	Frequency	Percentage
Advanced Forecasting and Demand Planning	58	9
Digital Supply Chain Platforms	75	12
RFID and IoT Tracking	79	12
Lean Manufacturing	121	19
Supplier Diversification	71	11
Data Analytics and AI	34	5
Vertical Integration	114	18
E-commerce and Online Marketplaces	30	5
Blockchain Technology	27	4
Automated Order Processing	34	5
Sustainable and Eco-friendly practices	1	0

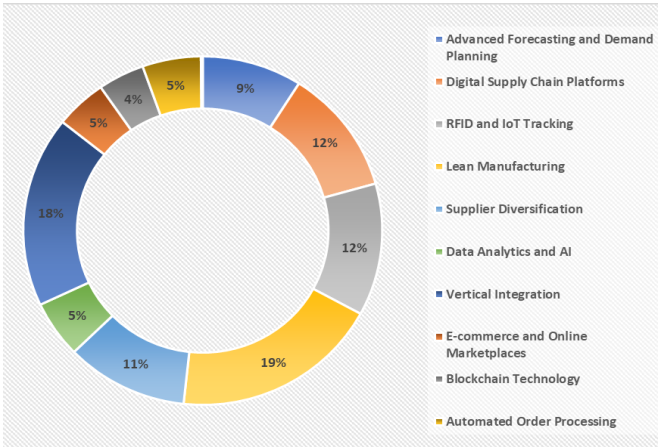

Fig. 2: Summary on potential to use technology and management techniques to reduce the lead time of raw material sourcing.

According to the table 2 and Fig. 2, lean manufacturing techniques, vertical integration digital supply chain platforms, RFID and IoT tracking and supplier diversification are the key potential implementation which can be done to reduce the cycle time for raw material sourcing for accelerated supply chains in apparel industry.

Survey feedback indicates that reducing cycle time in raw material sourcing offers substantial benefits to the Sri Lankan apparel industry, such as enhancing operational excellence and supply chain flexibility, as well as creating new business opportunities that enable growth and competitiveness in global markets. However, participants also highlighted significant challenges, notably the heavy reliance on overseas suppliers for specialty raw materials. This dependence increases risks related to sourcing cycle time, introducing uncertainties and making it difficult to control, while the need to maintain raw material stocks on hand adds significant storage and obsolescence costs.

Feedback received indicates that apparel manufacturers work closely with regional suppliers to improve supply chain management, forecasting, and communication in order to significantly reduce sourcing cycle time. Another key response was that increase in cycle time sourcing of raw materials forces apparel manufacturer to maintain raw materials stocks on hand generating massive expenses of storage and obsolesce.

V. Conclusion

The apparel manufacturing companies in Sri Lanka should focus on strengthening supply chain resilience through better quality control, transport logistics, forecasting to meet seasonal changes and implementing stronger communication channels. Diversifying supplier networks and employing advanced inventory management systems can also support to reduce the cycle time of raw material sourcing. Addressing these issues strategically may result in more efficient raw material sourcing and ultimately a more responsive and dependable supply chain.

It is imperative to address and mitigate factors which contribute to increased cycle time of raw material sourcing process. To reduce the quality control issues with suppliers, it is possible to implement supplier score cards, regular quality review meetings and monthly quality audits. Weekly meetings can be conducted with the supplier who is having the most critical quality issues in order to draw out actions plans with a timeline. Then the progress of the action plan would be monitored by setting follow up meetings. Establishing more reliable logistics partnerships and exploring alternative transportation methods to ensure timely deliveries by minimizing the transportation delays. Developing strategies for cost management, including bulk purchasing and long-term contracts with suppliers to lock in prices are recommendations for cost fluctuations.

The impact of seasonal variations can be curtailed through preplanned inventory and production schedules in advance to accommodate seasonal demands variations. It is apparent that the apparel industry views a combination of technological advancements and strategic operational adjustments as critical to reducing cycle times. Streamlining

communication channels between departments and with external supplier partners to prevent communication gaps and to ensure readily available information.

Implementing lean manufacturing principles, vertically integrating supply chains and embracing advance technology for improved monitoring and digital platforms for supply chain management are considered as key movements to make. Diversing suppliers and utilizing advanced data analytics, AI and automated processing are also viewed as vital for improving raw material sourcing responsiveness and efficiency.

Apart from that leverage of digitalization and data analytics can be recommended as another solution to reduce the cycle time of raw material sourcing and to accelerate apparel supply chains by paving way towards new technology era. Blue Yonder and GT Nexus support real-time demand forecasting and supply chain transparency, while Tableau, Power BI, and SAP AFS facilitate data analytics, visualization, and end-to-end production and inventory management. Digital transformative platforms such as data visualizing dash boards across operation to streamline processes, enhance decision making and improve communication can be implemented. Automated data analytic tools can be utilized to gain insights into operational bottlenecks, customer preferences and market trends forecasting and analysis. Future challenges for Sri Lanka's apparel industry may include managing the demands of rapid digital advancements and addressing supply chain vulnerabilities. To support resilience, the industry could focus on developing local supplier networks and adopting technologies like Artificial Intelligence forecasting and real-time tracking for improved agility and sustainability.

REFERENCES

[1] G. Gereffi and O. Memedovic, "The Global Apparel Value Chain: What Prospects for Upgrading by Developing Countries?" United Nations Industrial Development Organization, Vienna, Austria, 2003. [Online]. Available: https://www.unido.org/sites/default/files/2009-12/Global_apparel_value_chain_0.pdf

[2] P. Kosmol, A. Nowak, A. Ostrowska, and A. Aluchna, "Impact of Green Management on Product Quality: Analyzing the Role of Sustainable Production and Circular Economy in Manufacturing Firms," *Systems*, vol. 12, no. 11, pp. 456, Oct. 2023. [Online]. Available: https://www.mdpi.com/2079-8954/12/11/456

[3] Sri Lanka Export Development Board, "Apparel Industry Capability Report 2021," Colombo, Sri Lanka, 2021. [Online]. Available: https://www.srilankabusiness.com/ebooks/apparel-2021.pdf

[4] International Trade Administration, "Sri Lanka - Textiles," *Country Commercial Guides*, 2023. [Online]. Available: https://www.trade.gov/country-commercial-guides/sri-lanka-textiles

[5] M. Balasubramanian and P. Sheykhmaleki, "Comprehending the Consumer Behavior toward Sustainable Apparel," *Sustainability*, vol. 16, no. 18, p. 8026, 2024. [Online]. Available: https://www.mdpi.com/2071-1050/16/18/8026

[6] A. N. L. Ranasinhge, "Supply chain management issues in the apparel sector,"2018.[Online]. Available:http://dl.lib.uom.lk/bitstream/handle/123/14597/TH3672.pdf?sequence=3&isAllowed=n

[7] Sri Lanka Export Development Board, "Industry Capability Report: Apparel 2024," Colombo, Sri Lanka, 2024. [Online]. Available: https://www.srilankabusiness.com/ebooks/industry-capability-report-apparel-2024.pdf

[8] I I. J. Chen and A. Paulraj, "Understanding supply chain management: critical research and a theoretical framework," *International Journal of Production Research*, vol. 42, pp. 131-163, 2004. [Online]. Available: https://doi.org/10.1080/00207540310001602865

[9] K. Hitomi, "Strategic integrated manufacturing systems: The concept and structures," *International Journal of Production Economics*, vol. 25, no. 1-3, pp. 5-12, 1991. [Online]. Available: https://doi.org/10.1016/0925-5273(91)90125-D

[10] J. Lam and R. Postle, "Textile and apparel supply chain management in Hong Kong," *International Journal of Clothing Science and Technology*, vol. 18, no. 4, pp. 265-277, 2006. [Online]. Available: https://doi.org/10.1108/09556220610668491

[11] G. Gereffi, "International trade and industrial upgrading in the apparel commodity chain," *Journal of International Economics*, vol. 48, no. 1, pp. 37-70, 1999. [Online]. Availble: https://doi.org/10.1016/S0022-1996(98)00075-0

[12] P. Majumder and A. Srinivasan, "Leadership and competition in network supply chains," *Management Science*, vol. 54, no. 6, pp. 1189-1204, 2008. [Online]. Available: https://doi.org/10.1287/mnsc.1070.0752

[13] A. Agrawal, "Managing raw material in supply chains," *European Journal of Operational Research*, vol. 239, no. 3, pp. 685-698, 2014. [Online]. Available: https://doi.org/10.1016/j.ejor.2014.06.012

[14] J. R. Carter and R. Narasimhan, "Purchasing and supply management: Future directions and trends," *International Journal of Purchasing and Materials Management*, vol. 32, no. 4, pp. 2-12, 1996. [Online]. Available: https://doi.org/10.1111/j.1745-493X.1996.tb00225.x

[15] R. M. Monczka and R. J. Trent, "Global sourcing: A development approach," *International Journal of Purchasing and Materials Management*, vol. 27, no. 2, pp. 2-8, 1991.[Online]. Available: https://doi.org/10.1111/j.1745-493X.1991.tb00527.x

[16] K. J. Petersen et al., "An empirical investigation of global sourcing strategy effectiveness," *Journal of Supply Chain Management*, vol. 36, no. 2, pp. 29, 2000. [Online]. Available:https://doi.org/10.1111/j.1745-493X.2000.tb00075.x

[17] A. Z. Zeng, "Global sourcing: Process and design for efficient management," *Supply Chain Management*, vol. 8, no. 4, pp. 367-379, 2003.[Online]. Available: https://doi.org/10.1108/13598540310490125

[18] H. Forslund and P. Jonsson, "Integrating the performance management process of on-time delivery with suppliers," *International Journal of Logistics Research and Applications*, vol. 13, no. 3, pp. 225-241, 2010. [Online]. Available: https://doi.org/10.1080/13675561003712799

[19] R. B. Handfield and C. Betchtel, "The role of trust and relationship structure in improving supply chain responsiveness," *Industrial Marketing Management*, vol. 31, no. 4, pp. 367-382, 2002. [Online]. Available: https://doi.org/10.1016/S0019-8501(01)00169-9

[20] R. M. Grant, *Contemporary Strategy Analysis*, 7th ed. Oxford, U.K.: Blackwell Publishing, 2010.

[21]A. F. Cutting-Decelle, B. Das, R. Young, K. Case, S. Rahimifard, C. Anumba, and N. Bouchlaghem, "Building supply chain communication systems: A review of methods and techniques," *Data Science Journal*, vol. 5, no. 4, pp. 29-51, 2006. [Online]. Available: https://datascience.codata.org/articles/10.2481/dsj.5.29

[22] L. B. Forker, "Factors affecting supplier quality performance," *Journal of Operations Management*, vol. 15, no. 4, pp. 243-269, 1997.

[23] A. S. Carr and J. N. Pearson, "Strategically managed buyer-supplier relationships and performance outcomes," *Journal of Operations Management*, vol. 17, no. 5, pp. 497-519, 1999. [Online]. Available: https://doi.org/10.1016/S0272-6963(99)00007-8

[24] C. L. Garay-Rondero, J. L. Martinez-Flores, N. R. Smith, S. O. Caballero Morales, and A. Aldrette-Malacara, "Digital supply chain model in Industry 4.0," *Journal of Manufacturing Technology Management*, vol. 31, no. 5, pp. 887-933, 2020. [Online]. Available: https://doi.org/10.1108/JMTM-08-2018-0280

[25] V. Alcácer and V. Cruz-Machado, "Scanning the Industry 4.0: A literature review on technologies for manufacturing systems," *Engineering Science and Technology, an International Journal*, vol. 22, no. 3, pp. 899-919, 2019. [Online]. Available: https://doi.org/10.1016/j.jestch.2019.01.006

[26] R. Li, W. Liu, and S. Zhou, "Digital transformation of supply chain management in the fast fashion industry: A case study of Zara," *SHS Web of Conferences*, 2024. [Online]. Available: https://doi.org/10.1051/shsconf/202418104019

[27] Wu, C. Kopot, and L. Zhao, "Improving inter-functional coordination in apparel companies through digital transformation – An exploratory case study in China," *Bridging the Divide*, 2024 [Online]. Available: https://doi.org/10.31274/itaa.17224

Enhance the Online Fashion Purchasing Behavior among Digital Seniors: Quantitative Study

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Abstract— **The integration of digital technology into the lives of the elderly is increasing. It has greatly changed their shopping habits. Especially in the online fashion field This study explores the key factors influencing online fashion purchasing behavior among digitally-savvy people in Sri Lanka from 2022 to 2024, defined as those aged 60 years and above. The survey used quantitative methods to distribute to a sample of 30 digital seniors. Important information Behavioral drivers are defined. These findings highlight several important factors. Including the use of the website usages and Trust in online platforms convenience and targeted marketing strategies. In addition, accessibility features such as large text availability, screen readers, and a secure payment system It has been identified as a key element that increases the trust and confidence of elderly customers. This study highlights the importance of providing customer support and educational resources. To help digital seniors navigate online shopping platforms efficiently social influence Including recommendations from friends and positive word of mouth. It was found to have a significant impact on online purchasing decisions. The study concludes with recommendations for online retailers. The focus is on improving website usability. Security measures and personal marketing efforts to better meet the unique needs of digital seniors.**

Keywords- digital senior, Online fashion, e-commerce, usability, trust

I INTRODUCTION

Rapid advancements in digital technology have changed consumer behavior across age groups. significantly including the elderly people. With increased reliance on the internet for shopping, especially after the COVID-19 outbreak, senior people defined as those aged 60 and over, are increasingly engaging with digital platforms for a variety of purposes. including online fashion shopping. This population group is also known as digital seniors. It represents a growing segment that is actively adopting and interacting with digital technologies. Different from previous generations who may face challenges in using such tools Digital seniors are an important market segment for retailers.

The global aging population also highlights the importance of serving this group. According to the World Health Organization (WHO), the proportion of people aged 60 years and over will almost double from 12% to 22% by 2050, representing 2.1 billion people. This highlights the growing relevance of older consumers in the digital economy especially in emerging markets like Sri Lanka Even though the digital participation of seniors is increasing, their online purchasing behavior, especially in fashion has still not been properly researched.

Previous research has identified several factors that influence older adults' adoption of information and communication technology (ICT) [1]. This includes perceived ease of use. perception of benefits, social influence, and trust in digital platforms Understanding these factors is essential to improving the online shopping experience for digital seniors. This is because they face unique challenges, such as age-related physical limitations, low digital literacy, and concerns about online safety. For example, as digitally-savvy seniors use online technology for entertainment and communication, while a smaller proportion engage in e-commerce activities. Trust in online platforms, website usage, and secure payment options are a key factor influencing online purchasing decisions, considering the increasing participation of digital seniors in e-commerce, especially after the pandemic. Therefore, there is a clear need to investigate the factors that improve their online fashion purchasing behavior. This research aims to fill this gap by exploring the needs, preferences, and challenges of digital seniors in Sri Lanka. The study has been undertaken from 2022 to 2024. The findings will provide valuable insights for marketers. For policymakers, it allows them to target this demographic and to better address their specific needs while enhancing the online shopping experience.

Research Problem

This study mainly focused on enhancing online fashion purchasing by finding major contributing factors to enhancing the purchasing of digital seniors. This comes after the basic question, “How to enhance the online shopping behavior among this growing demographic group, and what are the factors for this? “

In addition to this main question, this research also concentrated on the effectiveness of using the principle of digital marketing and how digital marketers can tailor their products to this consumer group by identifying their specific expectations.

Objectives

1. identify and analyze the key factors influencing digital seniors' online fashion purchasing behavior and the factors that are affected to enhance online shopping behavior among digital seniors.
2. find out the platforms mostly engaged by digital seniors
3. Contribute knowledge for future researchers when selecting possible variables to investigate the topic of online shopping behavior of older adults and
4. Provide helpful information to Digital Marketers and policymakers.

A. Introduction to Digital Seniors and Online Shopping

The term digital senior refers to individuals aged 60 years and older who actively engage with digital technology in their daily lives. This demographic is different from previous generations of elders. They are increasingly comfortable with technology and benefit from greater access to the internet and mobile devices [2]. Online shopping among digital seniors has gained momentum in recent years. It is influenced by factors such as increased internet access. and ease of purchase Products from the comfort of home Online fashion purchases have increased dramatically It is driven by various economic, social, and technological factors [3].

B. Factors influencing online fashion buying behavior

Several studies have examined the factors that influence the online shopping behavior of digital seniors, especially in the fashion sector. These factors can be grouped into three main categories: Usability, Reliability (trust), and convenience.

I. Usability

Usability is one of the main concerns for older consumers engaging with online platforms. User-friendly websites with large fonts, simple navigation, and easy-to-read formats have been found to significantly improve the digital shopping experience for seniors [4]. This allows them to surf the web more conveniently. These enhancements cater to their unique and physical characteristics [5]. Cognitive needs of the elderly, especially those with weakened vision or limited experience would be highly impactive when using digital interfaces.

Also, user-friendly websites and accessibility features are key to catering to older consumers in online retail. This is especially true for fashion purchases as stated in online shopping for this demographic [6]. Easier steps and easy communication are essential to making the experience smooth.

II. Reliability and safety

Trust in online platforms, especially when it comes to the security of personal financial information is important for Seniors [7]. Many digitally-savvy seniors are wary of online transactions due to privacy and fraud concerns. To address these concerns e-commerce platforms have implemented strict security measures such as encryption, and secure payment gateways. and visible privacy policy. These measures help build trust among older consumers [8]. This is important in encouraging them to buy fashion online. As stated in [9], increasing trust through improved security measures has a positive impact on the adoption of online shopping among digital seniors.

III. Convenience

The convenience of shopping from home is one of the key drivers of online shopping, especially among senior professionals who are comfortable with digital platforms, especially in the fashion industry. This demographic tends to value the ability to compare products online and access a wider range of products than in physical stores [10]. Additionally, the availability of customer support such as live chat, telephone assistance, and more, and detailed questions and answers help digital natives solve the challenges they face while shopping online while improving the overall experience [11]. According to Rathnayake [12], these factors are important in driving the growth of online shopping among Sri Lankan seniors.

When considering the importance of customer support and educational resources to improve the online shopping behavior of digital seniors, especially fashion products, courses and guides provided by retailers help guide seniors through the complexities of online shopping platforms. This reduces barriers to perception and increases the likelihood of purchase [13].

C. Marketing strategies aimed at digital seniors

Customized marketing strategies have been developed for digital seniors to reflect the increasing digital literacy among this demographic. Targeted marketing such as email campaigns and advertising on platforms more used by seniors (such as Facebook) have proven effective in driving online fashion purchases in this segment [14]. These campaigns often highlight the benefits of shopping online, including convenience, accessibility, and product variety. This is in line with the needs of seniors in the digital world [15]. Ratnayake's study [16] also noted that personal marketing and word-of-mouth recommendations play an important role in influencing seniors' purchasing decisions.

D. Growth of online fashion shopping among digital seniors

There has been a noticeable increase in online fashion shopping among digital seniors. Especially during the COVID-19 outbreak. By accelerating the adoption of online platforms for everyday purchases. including fashion products Expand product categories relevant to elderly consumers, such as convenience and mobility [17]. Designed clothes has further driven this growth. Retailers are increasingly focused on providing products that meet the unique needs of seniors [18]. This is to ensure that this population group has easy access to relevant products.

Studies show that digitally-savvy seniors in Sri Lanka are turning to online fashion shopping due to its convenience and accessibility, and benefit from enhanced customer support and security measures [19]. And the ability to easily return products also increases confidence in buying fashion products online [20].

Research has found that the online shopping behavior of digital seniors is determined by several key factors such as website usability, security, convenience, targeted marketing, etc. In the fashion industry, providing an accessible platform builds trust through strong security measures and providing convenient and relevant products. Improving the online shopping experience for seniors is important. This is because the number of elderly people who are interested in digital usage is increasing, especially in Sri Lanka. These factors remain key to driving engagement with online fashion retailers.

II RESEARCH METHODOLOGY

This research uses a quantitative research design to explore the factors influencing the online fashion purchasing behavior of digital seniors in Sri Lanka. This structured approach ensures the reliability and validity of the findings.

A. Research design

This study uses quantitative methods to collect and analyze data related to the online shopping behavior of digital seniors. A structured questionnaire was created to collect information on demographic characteristics. use of technology, purchase preferences and factors influencing online purchasing behavior This methodology was chosen to quantitatively measure the digital behavior patterns and trends of older consumers. Focusing specifically on online fashion shopping [2].

B. Sampling

The target population consists of digitally-savvy seniors aged 60 years and above who actively use digital platforms for online shopping in Sri Lanka. Convenience sampling was used to select participants. This resulted in a sample size of 30. The sample was

intended to reflect the diversity of the target population by including participants from different areas. Although future studies may aim for a larger and more representative sample size to increase generalizability [3].

C.Collection of information

Data collection was conducted using an online questionnaire distributed through Google Forms. The questionnaire consisted of a mix of closed-ended and open-ended questions to gather quantitative and qualitative insights. The survey is designed to be intuitive and easy to use. It takes approximately 10-15 minutes to complete. Questions focus on areas such as digital literacy, trust in online platforms, and purchasing behavior. Using online surveys allows for broad access while maintaining respondent convenience [4].

D. Data analysis

The data collected was analyzed using descriptive statistics to summarize the demographic characteristics of the respondents and their online shopping habits. This includes measures such as frequencies, percentages, and averages. Thematic analysis was also used to identify patterns and themes in open-ended responses. It provides insights into seniors' motivations and challenges in online fashion shopping. Statistical analysis software was used to ensure the validity and reliability of the quantitative data [5].

E.Ethical considerations

Strict ethical standards were followed throughout the research process. Participants were fully informed about the purpose of the study and obtained informed consent before data collection began. Maintaining anonymity and confidentiality ensured that individual responses could not be traced back to the participant. The study followed ethical guidelines that are consistent with the institution's professional standards for conducting research involving human participants [6].

F.Limitations

The study acknowledges several limitations. First, the small sample size of 30 respondents limits the ability to generalize the findings to the broader digitally aging population. Second, the use of convenience sampling may cause bias, this is because the sample may not fully represent the diversity of Sri Lanka's digitally aging population. Future research should aim to include larger and more representative samples. To improve the robustness of the findings, furthermore, relying on self-reported data from online surveys may introduce response bias [7].

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G. Ethical and Data Collection Challenges

Research faces several challenges. In particular, there are limitations to the existing literature on the online fashion purchasing behavior of digital seniors in Sri Lanka. Expanding the sample beyond the initially planned Western Province area was necessary. Because the number of survey respondents using digital systems is limited.

This section concludes also with recommendations for future studies to address these limitations by expanding sample size and geographic representativeness. and exploring other qualitative methods such as in-depth interviews. To gain richer insights into the motivations and preferences of digital seniors [8].

III RESULTS

This section presents a comparative analysis of the survey results with 30 respondents, focusing on increasing online fashion purchasing behavior among digital seniors in Sri Lanka, from 2022 to 2024. Demographic analysis. use of technology online platform social influence online shopping features and settings Related charts and tables are displayed with explanations for better understanding.

1. Demographic information of the respondents

The survey reveals important insights into the demographic makeup of digital seniors who shop online. Table 1 summarizes the demographics of respondents.

Table 1: Demographic Classification of Respondents

Demographic Factor	Category	Frequency	Percentage
Gender	Male	9	30%
	Female	21	70%
Age	60–65 years	11	36.7%
	65–70 years	19	63.3%
Occupation	Retired	5	16.7%
	Still Working	7	23.3%
	Private sector Employee	10	33.3%
	Government sector Employee	4	13.3%
	Business Owner	2	6.7%
	Others	2	6.7%
Monthly Income	Less than LKR 25,000	4	13.3%
	LKR 25,000–50,000	8	26.7%
	LKR 50,000–75,000	7	23.3%
	Above LKR 100,000	6	20%

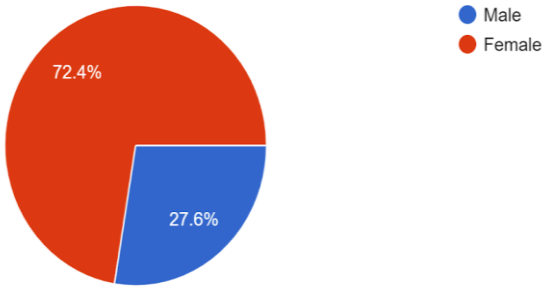

Figure 1: Gender of respondents

The majority of respondents were women (70%) according to the gender distribution within the sample.

Introduction of Technology and Usage Patterns

This study assessed respondents' comfort with technology, especially digital devices and internet access. The results showed that the majority of respondents (70%) reported that their comfort level with using digital devices was moderate to high. Based on this data, 36.7% of seniors indicated a comfort level of 4 out of 5, and 33.3% recorded a level of 3, indicating appropriate familiarity with online tools and platforms.

Table 2: Device usage for Internet access

Device	Frequency	Percentage
Smart(mobile) phones	24	80%
Laptops	12	10%
Tablets	2	6.7%
Desktops	1	3.3%

Using the required equipment, the majority of seniors (80%) prefer to use their smartphones to access online forums. This reflects the trend of increasing mobile internet use among the elderly. While laptops are the second most used device with 10%.

2. Trust in online shopping platforms

Trust is a key factor influencing online shopping behavior among digital seniors with 75% of respondents expressing strong satisfaction with platforms that offer transparent return policies and service options.

Table 3: Factors affecting trust in online shopping platforms

Trust Factor	Frequency	Percentage
Clear Return Policies	23	75%
Family or Friend Recommendations	18	60%
Customer Service Options	21	70%

The table emphasizes the importance of a clear return policy and word-of-mouth recommendations as key mechanisms for building trust. These findings indicate that digital seniors seek reassurance and verification before purchasing products online.

3. Social influence on purchasing decisions

Social influence plays a key role in seniors' purchasing decisions in the digital world, with 65% of respondents saying family and friends' recommendations heavily influence their choices.

Table 4: Social influences on purchasing decisions

Social Influence Factor	Frequency	Percentage
Family and Friend Recommendations	20	65%
Peer Discussions about Shopping	15	50%

This result indicates that the digital senior population relies heavily on information from their community and family. It emphasizes the role of social networks in influencing online shopping behavior.

4. Settings for online fashion shopping features

Respondents highlighted several key features that make their online fashion shopping experience more enjoyable. Its most important features include an easy-to-use interface. Detailed product description and customer reviews

Table 5: Preferences for online shopping features

Feature	Frequency	Percentage
User-Friendly Interface	26	85%
Detailed Product Descriptions	21	70%
Customer Reviews and Ratings	19	65%
Tailored Recommendations	16	55%

According to the table main features that increase efficiency in online shopping data shows that seniors prefer platforms that are easy to use. It includes comprehensive product descriptions and customer feedback. This finding is consistent with previous studies showing that older adults value simplicity and transparency in online transactions.

5. Improving the Online Shopping Experience: Gaps and Features Needed In terms of desired improvements

Table 6: Recommended features (*To improve online shopping experience*)

Desired Feature	Frequency	Percentage
Fit Guidance and Size Charts	17	54.8%
Clear Product Descriptions	12	38.7%
Visual Assistance Tools	10	32.3%
Senior-Friendly Discounts	5	16.1%

These findings suggest that it is important to improve the online shopping experience for seniors by improving product descriptions. More accurate size options are available and provide visual assistance tools.

6. Information and resources for online shopping

When asked what type of information or resource would be most helpful when shopping online, social media platforms have become the top choice with 48.4% of respondents relying on these platforms for product and trend information.

Table 7: Preferred resources for online shopping Source *(frequency percentages)*

Information Source	Frequency	Percentage
Social Media Platforms	15	48.4%
Recommendations from Peers	7	22.6%
Online Advertisements	5	16.1%
Fashion Blogs/Websites	4	12.9%

Data processing for fashion shopping. Social media plays an important role in online purchasing decisions. This reflects the increasing importance of digital platforms in the consumer journey for digital seniors

Table 8: Most preferable social media platforms

Digital Platforms	Frequency	Percentage
Facebook	23	76.7%
WhatsApp	19	63.3%
YouTube	17	56.7%
Instagram	9	30%
Tik-Tok	3	10%
Others	2	6.7%

The above table and below figure represent the most preferable platforms for older adults. The highest percentage was recorded by Facebook as 76.7% of adults preferred Facebook which was the most popular platform among older adults. Preference for YouTube and WhatsApp is more than 50% percent. 30% percent of older adults preferred to use Instagram and preference for TikTok was 10% percent. For the others selected 6.7%. (Note: this question is a multiple-choice question and respondents were given the option to choose more than one answer.

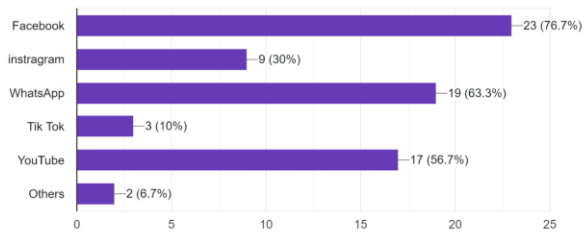

Figure 2: The Most preferable social media platforms

The results of this study reveal the factors affecting the online fashion buying behavior of digital seniors in Sri Lanka. Research shows that trust, social influence, User-friendly platforms, and a tailored shopping experience are important factors for this demographic. In addition, improvements to certain features such as tailored navigation and product descriptions will help improve the online shopping experience.

IV Discussion

Survey results and data analysis indicate that technological familiarity is a key factor in enhancing the online shopping experience for digital seniors in Sri Lanka in 2022-2024. Many digital seniors still experience problems with online platforms. This is often due to a lack of digital knowledge. This study supports the idea that greater exposure to technology leads to better comfort levels when using online fashion platforms.

A key recommendation is for online retailers to invest in educational initiatives. Includes a simple tutorial and accessible advice. This can help seniors navigate complex websites more easily. This is consistent with previous research that promotes seniors' engagement with online platforms. Emphasize the importance of increasing Digital knowledge at the middle level [6].

4.1 Challenges in online fashion shopping: findings vs. conclusions

The challenges digital seniors face when shopping for fashion online is consistent with existing literature on the topic. Responses revealed dissatisfaction with the complicated ordering process. Problems with product size and distrust regarding product quality. Despite various challenges, the study emphasizes that addressing these challenges holistically can lead to better user satisfaction. By simplifying the user interface Provide a detailed size chart. and guarantees transparent product descriptions. Retailers can reduce confusion and improve the shopping experience. Where users are over 65 years of age, in contrast to more complex designs. which shows that they are higher Engagement rate (72%) with websites that make navigation easier.

The results also suggest that social influence and trust play an important role in motivating this group. Digital seniors are heavily influenced by reviews, testimonials, and word-of-mouth marketing. Retailers should consider this and leverage social proof strategies to build trust. For example, including customer testimonials in key sections of the website can alleviate fears about quality, suitability or returns. Because social validation serves as the main motivator.

Especially when considering the question “How comfortable are you using digital devices and the internet” is a closed-ended structure question. It utilizes a Likert scale to measure respondents' comfort level with using digital devices and the internet, ranging from 1 to 5, where 1 represents very uncomfortable and 5 represents very comfortable. The comfort with digital devices and usage by percentage and frequency can be illustrated as follows below in Figure 3.

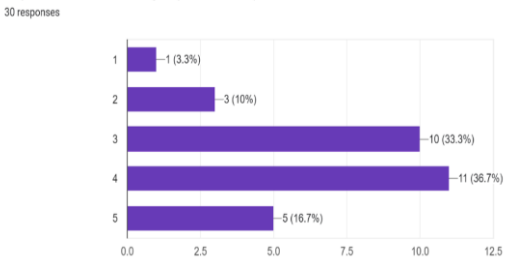

Figure 3: comfort level with using digital devices and the internet *(ranging from 1 to 5)*

Having 36.7% of respondents refer in point 4 within the Likert scale as comfortable means they are not more confident with using digital devices and the internet but they are comfortable and manageable with as so far. Furthermore, 33.3% of answers for point 3 implicated they were comfortable with digital devices and the internet in the mean level. But there is only one respondent for point one, so that means there were limited persons in this older age range very uncomfortable with digital devices and internet usage.

Analyze the preferred online shopping of older adults

The question “Do you prefer to shop online” (Note – This is a direct question, so the answers are only yes or no) 74.2% responded “Yes” and only 25.8% responded as they did not prefer online shopping, so their answer is “NO”. Figure 4 shows the respondents and percentages.

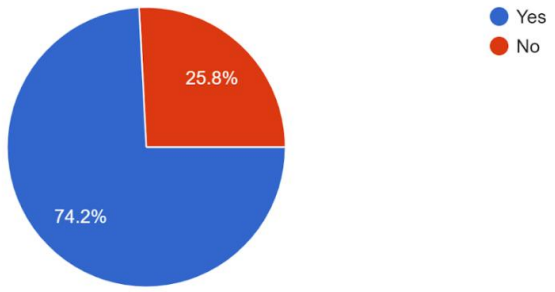

Figure 4: preference for Online shopping or physical shopping

For the question "Do you prefer online shopping?" (Previous question) if they respond as "yes" or "No", this question is to describe why they like or not. There are only 19 responses. The respondents are given below in Table 9.

Table 9: quoted reasons for above answers (*Yes or No)*

If said "YES"	**If said "NO"**
An easy method of shopping	No required designs
It is very easy	Cannot choose the right size without fitting it
It is easy and time is saved	I want to touch the things before purchasing them
It is easy to do the transactions	Not comfortable as usual physical shopping
Can find variable fashion online	Most of the time can't trust some online shopping platforms.
I have done shopping using apps like Daraz and Ali Express	Time waste
I normally buy clothes online because it saves me time. And it's easy to select the wanted designs	
It saves me time. I'm a busy man so I don't have much time to go shopping	
No, I like shopping physically	
I ordered food and some clothing and other cosmetic products	

When summarizing the answers, they said they like to shop online because of time-saving and ease of shopping. Furthermore, if analyze why older adults do not prefer online shopping the most answers are as follows, they do not like to go out of their habitual physical shopping, they are not comfortable with online shopping, also the other reason is that they do have not suitable design and sizes at the online store.

4.2 To overcome dissatisfaction with online fashion shopping

The study reveals key reasons for digital seniors' reluctance to shop for fashion online Most of these involved concerns about quality, trustworthiness, and high prices. According to the results, the most frequently cited reasons for avoiding online shopping. By showing that "Poor product quality" and "difficulty in evaluating size and fit" were the most frequently mentioned issues.

To address these concerns Retailers can introduce features such as zoomable images and 3D product views so that shoppers can clearly understand product contents and dimensions. It also addresses these concerns by integrating virtual fitting rooms and AI-powered sizing guidance, which is helpful. When considering zoom and view functions are combined. Dimensions resulted in a 35% reduction in product returns among users aged 60-70 years in related studies.

Additionally, fear of fraud or misuse of personal information remains a barrier for many digital seniors. Building trust by providing clear information about our return policy, maintaining secure payment options and transparent customer service is an important strategy for increasing trust in online transactions [7].

4.3 To enhance the user experience for digital seniors

Improving the user experience on online fashion platforms is essential to increasing adoption among digital seniors. Research indicates that many respondents prefer an easy-to-use platform with simple navigation and easy-to-understand product descriptions. Research indicates that good design and user interfaces contribute to a positive shopping experience and higher satisfaction [9].

Integrating elements such as intuitive navigation larger font size, high contrast color scheme, and voice shopping assistance system, accessibility can be greatly improved. Also, digital seniors engage with websites that are optimized for accessibility features. As a behavioral online purchasing rate has been increased it has been visualized, how they report higher levels of satisfaction with their overall online purchases.

4.4 Build trust in the online shopping ecosystem

The importance of trust in digital transactions, especially among the elderly, cannot be overstated. Research continues to show that transparent communication about data privacy, Return Policy, and secure payment options is essential to earning the trust of digital seniors [7]. This study reinforces the need for retailers to certify the reliability of their services to promote repeat purchases and the relationship between customer trust and the likelihood of repeat purchases. It shows that seniors who trust the platform are 40% more likely to participate in future purchases.

Retailers should focus on building relationships through excellent customer service. clear communication and consistent product quality. Additionally, frequent communication about order updates and convenient returns procedures will help reduce this age group's concerns about online shopping.

4.5 Future research directions

Future research is needed to explore how emerging technologies such as augmented reality (AR) and artificial intelligence (AI) can improve the online shopping experience for digital seniors. These technologies have the potential to make online fashion shopping more interactive and personal, which meets the needs of this demographic. Additionally, a long-term study that tracks changes in digital seniors' online shopping behavior over time. It provides valuable insights for retailers aiming to improve their engagement strategies.

V RECOMMENDATIONS

The study offers several key recommendations to increase online fashion buying behavior among digitally-savvy seniors in Sri Lanka:

1. Customizable Marketing Strategy

Fashion marketers are using targeted strategies that emphasize convenience, discounts, and accessibility. Websites should be designed with an easy-to-use interface and features such as saved settings. and one-click purchasing to improve the experience. Discounts and promotions such as "senior discounts" and "loyalty programs" can encourage purchases. and should be prominently displayed to attract digital seniors (Yusuf, 2022) [1]. Accessibility can be further improved by providing multiple customer support channels, such as live chat, phone, and email, with smooth navigation menus, and simple and adjustable font size [3].

2. User-friendly platform design

To enhance the shopping experience, the platform must have clear product descriptions. Detailed size tables and user-friendly navigation features such as zoomable images and user-friendly interfaces help address senior citizens' concerns about product quality and fit [21].

3. Improved customer support

Providing accessible customer support is essential to building trust among digital seniors. Companies should offer a variety of communication channels, such as live chat, phone support, and email, to accommodate different priorities. In addition, the support interface must be easy to use, with clear contact information and quick, personalized responses to seniors' needs. Educational resources including instructional videos and FAQs can help seniors use online shopping platforms with confidence (Yusuf, 2022) [1].

4. Install navigation aids for different sizes and visual assistance.

Online forums should have appropriate sizing guidance tools, such as detailed sizing charts. and virtual fitting room. To reduce size problems. 360-degree product viewing, video display, and virtual trial technology can help digital seniors make better purchasing decisions by providing more visual information about products [3].

VI CONCLUSION

This study attempts to improve online fashion buying behavior by examining factors that affect their experience among digitally-savvy seniors in Sri Lanka. and address the challenges they face. These findings provide important insights into how retailers can tailor their offerings to demographics, trust, convenience, and convenience and how can users get better at it. Sociability focuses on important areas like the interface. The demographic analysis found that digital seniors, mostly between the ages of 60 and 70, are moderately comfortable with technology according to the sample within Colombo. Smartphones are the most popular device for online shopping. Platforms like Facebook are the most popular among this sample. This points to the importance of such targeted marketing strategies. Additionally, discounts, promotions, and the time-saving nature of online shopping were identified as strong motivators for this demographic. This is consistent with previous studies on the shopping preferences of older adults [22].

Several challenges were highlighted; including a complex ordering process, size tolerances, and product quality and reliability concerns. These obstacles (if fixed) could significantly improve the digital shopping experience for seniors. Trust becomes an important factor in decision-making. This reinforces the need for a clear return policy. Strong customer support and transparent communication with sellers [23]. Additionally, social influences such as recommendations from family and friends play an important role. It emphasizes the need for retailers to leverage social proof and build trust through testimonials and reviews [24].

Easy-to-use platforms with clear product descriptions, the right navigation tool regarding different sizes, and visual assistance (e.g., 360-degree views, virtual reality experiences) have been identified as essential to improving the online experience and by dealing with these factors retailers can increase customer satisfaction and promote loyalty among digital seniors

In summary, this study highlights the importance of addressing the unique needs of digital seniors. To improve their online fashion buying behavior, future research should examine the long-term effects of emerging technologies such as augmented reality and artificial intelligence on the shopping experience of this demographic group. Addressing these changing priorities will be key for retailers aiming to effectively engage with this growing segment.

I. REFERENCES

[1] [1] D. M. Yusuf, "ICT adoption and online shopping among older adults," *Journal of Consumer Research*, vol. 16, no. 2, pp. 100-115, 2020.

[2] U. Rathnayake, “Digital seniors and online shopping: An emerging trend,” Journal of Digital Economy, vol. 12, no. 1, pp. 45-67, 2021.

[3] K. A. Ismail, "Enhancing online shopping behavior among older consumers," Sri Lanka Consumer Journal, vol. 9, no. 3, pp. 23-35, 2022.

[4] K. A. Ismail, "User-friendly website design for older consumers," *Sri Lanka Consumer Journal*, vol. 9, no. 3, pp. 26-27, 2022.

[5] U. Rathnayake, "Accessibility features in e-commerce: Catering to digital seniors," *Journal of Digital Economy*, vol. 12, no. 1, pp. 55-57, 2021.

[6] K. A. Ismail, “The role of website usability in online shopping,” *Sri Lanka Consumer Journal*, vol. 9, no. 3, pp. 30-32, 2022.

[7] U. Rathnayake, “Perceived trust and security among digital seniors,” *Journal of Digital Economy*, vol. 12, no. 1, pp. 48-50, 2021.

[8] K. A. Ismail, “Security measures in e-commerce: Building trust among older consumers,” *Sri Lanka Consumer Journal*, vol. 9, no. 3, pp. 28-29, 2022.

[9] U. Rathnayake, “Trust in online shopping among older adults: A case study,” *Journal of Digital Economy*, vol. 12, no. 1, pp. 60-61, 2021.

[10] K. A. Ismail, “The convenience factor in online shopping for digital seniors,” *Sri Lanka Consumer Journal*, vol. 9, no. 3, pp. 33-34, 2022.

[11] U. Rathnayake, “Customer support and the online shopping experience,” *Journal of Digital Economy*, vol. 12, no. 1, pp. 58-59, 2021.

[12] U. Rathnayake, “Growth of online shopping among Sri Lankan digital seniors,” *Journal of Digital Economy*, vol. 12, no. 1, pp. 65-66, 2021.

[13] K. A. Ismail, “Educational resources for digital seniors: Enhancing the online shopping experience,” *Sri Lanka Consumer Journal*, vol. 9, no. 3, pp. 36-37, 2022.

[14] K. A. Ismail, “Targeted marketing strategies for digital seniors,” *Sri Lanka Consumer Journal*, vol. 9, no. 3, pp. 40-42, 2022.

[15] U. Rathnayake, “Marketing strategies in online fashion retail: A focus on digital seniors,” *Journal of Digital Economy*, vol. 12, no. 1, pp. 68-70, 2021.

[16] U. Rathnayake, “Word of mouth and consumer behavior among older adults,” *Journal of Digital Economy*, vol. 12, no. 1, pp. 75-76, 2021.

[17] U. Rathnayake, “The rise of online fashion shopping among digital seniors,” *Journal of Digital Economy*, vol. 12, no. 1, pp. 80-81, 2021.

[18] K. A. Ismail, “Product variety and online fashion retail for older consumers,” *Sri Lanka Consumer Journal*, vol. 9, no. 3, pp. 45-46, 2022.

[19] U. Rathnayake, “Impact of customer support on online shopping growth,” *Journal of Digital Economy*, vol. 12, no. 1, pp. 85-86, 2021.

[20] K. A. Ismail, “Flexible return policies in online shopping: Reducing barriers for older adults,” *Sri Lanka Consumer Journal*, vol. 9, no. 3, pp. 48-49, 2022.

[21] U.C. Rathnayake, and Department of Fashion, Textiles, and Clothing Technology, Sri Lanka Technological Campus, “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,” conference-proceeding, 2023. doi: 10.13140/RG.2.2.28350.29764.

[22] Kim, J. (2017). The changing landscape of aging: Digital seniors. Journal of Gerontology, 72(3), 456-467.

[23] Patel, R. (2019). Trust and online shopping: A review. Journal of Retailing and Consumer Services, 50, 123-130.

[24] Smith, A., & Jones, B. (2018). Factors influencing older adults' ICT adoption. International Journal of Information Management, 34(2), 123-130.

EXTENDED ABSTRACT

Management Science

The Tourist's Perception and Uniqueness of the Sri Lankan Tea Tourism Experiences with reference to Nuwara Eliya District in Sri Lanka

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Abstract - Sri Lanka is a famous tourist destination around the world. The scenic beauty, cultural heritage, abundant wildlife, substantial wildlife, and toasty climate provide enormous value to "The Pearl of the Indian Ocean," making it a world-famous tourist destination (Jolliffe et al., 2022). With that, even though there were lots of ups and downs in the Sri Lankan tourism industry in recent years, Sri Lankan tourism recorded a remarkable over 1.9 million tourist arrivals in 2019. According to DailyFT, (2023), Sri Lanka is ranked as one of the top places to visit in the Europe and Asia region for 2023 DailyFT (2023). The tourism industry is one of the fastest-growing economic sectors. In Sri Lanka, this has contributed directly and indirectly to economic development (Punchihewa, 2020). As a result of British colonial growth, the tea industry emerged in Sri Lanka, with historical places in scenic hill country tea estate surroundings (Aslam and Jolliffe, 2015). When developing teabased tourism, it brings double economic benefits to Sri Lankan tourism, and this industry will be strengthened by more promotion and the consumption of tea and authentic tea culture experiences in Sri Lanka (Jolliffe and Aslam, 2009). Tea tourism experiences have been identified as one niche tourism segment under the emerging novel concept of nature- based tourism (Fernando et al., 2017). Tea tourism in Sri Lanka is one of the niche markets to support economic development, and it has attracted different market segments. Instead of only being consumed, the tea product is presented as a unique opportunity for tourists to be engaged in an authentic, immersive experience, where the journey from leaf to cup is showcased within the factories where it is produced. By combining tea-producing and tourism, tourists create a stronger connection to the destination and enhancing the area's attractiveness and reputation.

Key words - Tea industry, Tea Tourism, Ceylon Tea, Tourist Perception, Tourist Satisfaction

1. Introduction

Tea tourism in Sri Lanka is a unique and well-known segment of the country's broader tourism business. The purpose of the study is to illuminate the complexities of tourists' perspectives and to identify the unique value proposition hidden in the Sri Lankan tea tourism experience. The study travels across the stunning tea estates of Nuwara Eliya, focusing on qualitative data collected data from structured interviews with tourists drawn in by the attraction of tea tourism. The study identifies critical gaps in the tea tourism sector, emphasizing the importance of developing an extensive understanding of travelers' perceptions. The article focuses on the industry's issues, such as the inability to properly market the legendary Ceylon Tea. In addition, the study descends into the joint efforts of many stakeholders including the need for customer feedback channels to improve the entire tea tourist

experience. According to the findings, tourists highly value engaging in activities such as tea cultivation processes, tea tasting sessions, and

cultural events, emphasizing the importance of these immersive experiences in fostering enhanced brand loyalty and positive word-of-mouth promotion for the tea tourism sector. The thematic analysis of structured interviews revealed that Sri Lankan tea tourism is distinguished by its scenic beauty, educational value, and historical significance. Significant impacts on tourists' expectations were noted from visual materials. The appeal of tea production and Ceylon Tea's historical context enhanced the experience, highlighting the need for authenticity and improvement.

Research Questions

What is the tourist's perception on the Sri Lankan tea tourism experience?

What is the unique value behind the Sri Lankan Tea Tourism experiences?

Research objectives

To identify the tourists' perception on the Sri Lankan tea tourism experiences.

To recognize the unique value behind the Sri Lankan tea tourism experiences

1. Literature review

The literature reviews of the tourist's perception on the Sri Lankan tea tourism experience and the unique value behind the Sri Lankan tea tourism. Tea tourism has been defined as a means of generating local revenue and reducing poverty (Jolliffe and Aslam, 2009). According to the Sri Lankan context tea tourism is a niche tourism industry as a unique segment of the tourism industry, and tea tourism has product diversification under the niche tourism industry (Herath and Munasighe, 2014). By providing experiential exposure to Sri Lanka's comprehensive tea culture, tea tourism serves as a strategic facilitator for the promotion of Ceylon Tea's brand image (Dissanayake and Koththagoda, 2017). Tea tourism directly involves existing tourism practices of small tea holders and indirectly involves existing tea tourism products of small tea holders such as providing homestay and other accommodations, tour guiding, safari jeep service, community-based eco-camping and food, and shopping (Dedunu and Aslam, 2022). It is crucial for the stakeholders to appropriately improve and align tourism- related products, considering the impact of tea on tourists' inclusive satisfaction and fulfillment (Gupta et al., 2020).

Through tea, travelers are able to revisit how the self and the world interact in a calm environment that differs from their hectic everyday routines (Su & Zhang, 2020). Tourist perceptions of tourism are guided by the emotional connection with the residents in a particular destination (Joo et al., 2019). The perception of the tourists can be improved further by improving the quality and standards of the destination-related factors (Gnanapala, 2015). After the arrival of James Taylor in Sri Lanka, the commercial tea plantation has developed. Tea tourism has provided the natural environment for tea plantation activities such as tea leaf plucking, tea production, packing, and the culture of tea labor (Datta, 2018). Therefore, Sri Lanka's tea industry varies in quality, taste, and aroma based on agro-climatic conditions, but companies lack of effective marketing strategies to gain a competitive advantage (Hilal and Mubarak, 2016).

Research methodology

The most scenic tea plantations are located in Central Province; hence, the sample has been chosen from Nuwara Eliya district tea estates. Lee Jolliffe's journal has identified the use of tea in hospitality in Sri Lanka. It has mentioned tea-related tourism experiences in Sri Lanka. This tea destination has cultural and geographical value for the tourism industry. Qualitative data is collected in this study through questionnaires and interviews. To carry out this research using qualitative data to discover tourists' perception of tea tourism experiences. Participation in the research will be voluntary for all participants. The research philosophy for tourists' perceptions of the Sri Lankan tea tourism experience corresponds with interpretivism. Interpretivism, which is frequently referred to as constructivism, is a philosophical approach that emphasizes the importance of understanding the subjective meanings and interpretations that people make about their tourists have arrived in Sri Lanka with an awareness of Ceylon tea. Further, the tourists have a big image of Ceylon tea (Fernando et al., 2017). With the enhancement of the travel experiences and changes to the gradual lifestyle of the tourists, the cultural and leisure tourism experiences of the tourists become more popular. Therefore, tea industry-based experiences have been accepted by tourists as ways to relax (Zhou et al., 2023). Furthermore, tea tourism-related activities can be increased to enhance visitor attraction to the tea tourism industry. Railway transportation has operated in tea- producing communities, and tea growing communities included railways to provide tea and other services before serving tourists (Jolliffe,2007).

According to the above facts, in Sri Lanka's central province, tea plantations and the history of railway transportation have combined. Considering the qualitative characteristics of this study, a thorough and complete assessment of relevant literature is required to establish a sound theoretical foundation and contextual understanding. By examining previous studies, the study can obtain insights into the topic, find gaps in the literature, and establish a sophisticated understand of the subject matter. The community livelihood diversification in tea tourism destinations is developed through their engagement in tea growing and processing to provide tea tourism experiences (Su et al., 2019). The community can engage to provide authentic tea related experiences to the travel and tourism industries. The stakeholders in the tea tourism industry can use local community engagement to promote the industry. Tourists looking for relaxation and pleasure are said to enjoy tea industry-related experiences. However, it is crucial to evaluate if these experiences contribute to tourism practices and meaningful community engagement.

Interpretivism is appropriate for the context of this study due to its ability to enable an in-depth investigation of tourists' perceptions, feelings, and interpretations of tea tourism experiences in Sri Lanka. Interpretivism supports a qualitative research approach, which allows for in-depth interviews, observations, and textual data analysis to reveal the hidden complexities of tourist perspectives. The tourist's perception of tea tourism is being investigated in this study. Structured interviews are designed to collect standardized information from participants by asking an organized set of questions. In the framework of this study, structured interviews are considered a great method for systematically analyzing tourists' perspectives on tea tourism in Sri Lanka. Using a qualitative research approach, the study aims to reveal hidden aspects of travelers' opinions and observations, providing significant insights into the particular context of tea tourism in Sri Lanka. The research strategy offers a qualitative approach to investigating tourists' perceptions about Sri Lankan tea tourism. Data is gathered primarily using structured interviews, providing a targeted and methodical approach to obtaining information. The interviews are aimed at eliciting thorough responses from travelers regarding their experiences and perspectives on tea tourism. Thematic analysis is employed as the primary data analysis technique to identify patterns, themes, and meanings in the qualitative data. This method provides for a thorough examination of the distinct values related to Sri Lankan tea tourism, resulting in a deeper appreciation of the tourists' perspectives.

All ethical considerations, such as informed consent and participant confidentiality, are carefully followed throughout the research procedure. The research uses a qualitative method, including structured interviews and theme analysis, to unravel the complicated patchwork of experiences and values associated with this specialized tourism market. The findings have the potential to provide significant insights for policymakers, government organizations, travel agents, tea estate owners, and practitioners as they develop strategies to improve the attractiveness and long-term development of Sri Lankan tea tourism. The study's selection is consistent with a comprehensive exploration, providing a deeper knowledge of thble According to SLTDA (2022), Nuwara Eliya District has reported the highest tea production district in Sri Lanka. Therefore, Nuwara Eliya district can be the study area of this research. Upcountry agriculture plays an essential to the local and global markets because it produces a wide range of unique items, including fresh flowers, exotic vegetables, fruits, and the world-famous highland Ceylon tea (Ranagalage et al., 2019).

Data Analysis and Discussion

The study explores tourists' perceptions of tea tourism in Sri Lanka, focusing on Nuwara Eliya. It uses thematic analysis to examine data from 13 structured interviews, identifying key themes and patterns. The impact of pre-existing visual representations, such as pictures and videos, on the establishment of expectations before engaging in tea tourism activities is investigated. The role of social media in spreading these visual representations and their impact on tourist expectations is also analyzed. A limited picture of tea tourism in Sri Lanka is held by tourists before experiencing it. In addition, participants actively participated in the commercial component, indicating a greater desire to participate in purchasing tea products than observed. Tourists have had a desire to see around and touch tea even before coming to Sri Lanka.Tourists are motivated by curiosity about Ceylon tea's history and production when engaging in tea tourism in Sri Lanka. The discovery of the tea-making process and new experiences are sought, along with an understanding of the cultural significance of tea. Satisfaction and empathy for workers are felt, enhancing the overall experience, with educational and meaningful engagement being highlighted.

The unique cultural elements of Sri Lankan tea tourism were appreciated, with the distinctiveness of the experience, exceptional hospitality, and high-quality tea being praised. Positive feedback highlighted the tea-making process, the welcoming atmosphere, and the authenticity of freshly sourced vanilla tea, contributing to a highly satisfying and memorable visit. Dissatisfaction was noted with rushed tea factory tours and limited engagement during processing.

Memorable aspects included the discovery of unique tea varieties, witnessing traditional machinery, and experiencing the lush environment. Tourists emphasized the unique value of Sri Lankan tea through its historical production, high quality, and distinct fragrance. These elements contributed significantly to the perceived uniqueness and authenticity of the experience. Sri Lankan tea was compared favorably to teas from other countries, with its superior taste and distinct aroma being highlighted. The detailed and fresh explanations provided during the visit were also noted as distinguishing features. Recommendations included expanding tea flavor options, extending safari durations, and enhancing transparency in tea processing. The need for less commercialized and more immersive experiences was also emphasized. Tourists expressed a strong desire to return to Sri Lankan tea tourism, driven by positive experiences and satisfaction with the unique aspects of the visit. Tourists suggested offering a wider variety of tea flavors, prolonging safari experiences, and providing deeper insights into tea-making processes. Concerns about the commercialized nature of the tours indicated a preference for more authentic experiences. The interest in Sri Lankan tea tourism was driven by the appeal of the tea production process and the historical significance of Ceylon Tea. The lush landscapes and expansive tea fields were noted for providing a visually captivating backdrop. The complexity of tea-making and the historical context were recognized as enhancing the experience. For tea tourism operators, addressing these expectations and enhancing authenticity is deemed essential for creating a more engaging and meaningful experience. Future studies that can explore the uniqueness of tea could involve comprehensive investigations of various tea flavors, production procedures, and historical contexts, offering light on the aspects that distinguish Sri Lankan tea. In addition, future studies might concentrate on marketing tactics and product development in the tea tourism sector, identifying novel techniques to attract and engage travelers.

References

[1] Abeykoon, H.M. (2023) 'Collaborative Market-Driving Strategy for Tea Tourism in Sri Lanka', *Ceylon Today* , 15 July

[2] Daily News (2018) 'Lonely Planet ranks Sri Lanka as world's #1 travel destination 2019', *Daily News*, 24 October.

[3] Daily News (2020) 'Beyond the cup of tea', *Daily News*,25 August.

[4] Daily (2023) 'Forbes ranks Sri Lanka among top 23 Best Places to Travel this year, chosen by experts', *DailyFT*, 5 April.

[5] Fernando, P.I., Rajapaksha, R.M. and Kumari, K.W. (2017) 'Tea tourism as a marketing tool: A strategy to develop the image of Sri Lanka as an attractive tourism destination', *Kelaniya Journal of Management*, 5(2), pp. 64–79. doi:10.4038/kjm.v5i2.7518.

[6] Jolliffe, L. and Aslam, M.S.M. (2009) 'Tea heritage tourism: Evidence from Sri Lanka', Journal of Heritage Tourism, 4(4), pp. 331–344. doi:10.1080/17438730903186607.

Jolliffe, L. et al. (2022) 'Routledge Handbook of Tea Tourism',

[7] Tea tourism in the global south: An African perspective [Preprint]. doi:10.4324/9781003197041.

[8] Kumarihami, H.M. and Song, K.J. (2018) 'Review on challenges and opportunities in Global Tea Industry', The Korean Tea Society, 24(3), pp. 79–87. doi:10.29225/jkts.2018.24.3.79.

[9] N. Fernando, I. (2015) 'What competitive strategies way forward the regional competitiveness? A comparative economic approach to Sri Lankan tourism', International Journal of Business and Management, 10(4). doi:10.5539/ijbm. v10n4p178.

[10] Punchihewa, N.S. (2020) 'Intellectual property rights for tourism-related traditional knowledge: A case study of sri lanka', Sri Lanka Journal of Advanced Social Studies, 10(1), p. 76. doi:10.4038/sljass.v10i1.7158.

[11] Dilshan, K.M.M., 2023. Market Feasibility Of Establishing A New Tea Center: A Study Of Kelani Valley Plantations (Doctoral Dissertation, Uva Wellassa University).

[12] Silva, C.D. (2023) 'Tea Board Chief regrets tourism industry failure to promote world-famous Ceylon Tea', DailyFT, 2 June.

[13] Sri Lanka Tourism Development Authority (2018) 2018 Annual Statistical Report. rep. Colombo 03, Sri Lanka: SLTDA , pp. 01–117.

[14] Sri Lanka Tourism Development Authority, R. and international relation division (2022) Year in Review - 2022. rep. Galle Road Colombo 03, Sri Lanka: SLTDA, pp. 01–21.

[15] Su, X. and Zhang, H. (2020) 'Tea drinking and the tastescapes of wellbeing in Tourism',Tourism Geographies, 24(6–7), pp. 1061–1081. doi:10.1080/14616688.2020.1750685.

[16] Wimalagunasekara -, T. (2022) Industry Capability Report. rep. Sri Lanka Export Development Board (EDB), pp. 01–08.

Aslam, M.S.M. and Jolliffe, L. (2015) 'Repurposing colonial tea heritage through historic lodging', Journal of Heritage Tourism, 10(2), pp. 111–128. doi:10.1080/1743873x.2014.985226.

[17] Gupta, V. et al. (2020) 'Foreign Tourist's tea preferences and relevance to destination attraction in India', Tourism Recreation Research, 47(4), pp. 428–442. doi:10.1080/02508281.2020.1841376.25]

[18] Gnanapala, W.A., 2015. Tourists perception and satisfaction: Implications for destination management. American Journal of Marketing Research, 1(1), pp.7-19.

[19] Joo, D., Cho, H. and Woosnam, K.M. (2019) 'Exploring tourists' perceptions of tourism impacts', Tourism Management Perspectives, 31, pp. 231–235. doi:10.1016/j.tmp.2019.05.008.

[20] Herath, H. and Munasighe, S. (2014) 'Investigation into the Low Demand for Niche Tourism with Special Reference to Tea Tourism in Uva Province ', International Conference on Business and Information (ICBI, 2014), Kalaniya University, Sri Lanka [Preprint].

[21] Rickly-Boyd, J.M. (2012) 'Authenticity & aura', Annals of Tourism Research, 39(1), pp. 269– 289. doi:10.1016/j.annals.2011.05.003.

[22] Fernando, P.I., Rajapaksha, R.M. and Kumari, K.W. (2017) 'Tea tourism as a marketing tool: A strategy to develop the image of Sri Lanka as an attractive tourism destination', Kelaniya Journal of Management, 5(2), pp. 64–79. doi:10.4038/kjm.v5i2.7518.

[23] Datta, C. (2018) 'Future prospective of tea-tourism along with existing forest-tourism in Duars, West Bengal, India', Asian Review of Social Sciences, 7(2), pp. 33–36. doi:10.51983/arss2018.7.2.1434.

[24] Su, M.M., Wall, G. and Wang, Y. (2019) 'Integrating tea and tourism: A sustainable livelihoods approach', *Journal of Sustainable Tourism*, 27(10), pp. 1591– 1608. doi:10.1080/09669582.2019.1648482.

[25] Wipulasena, A., 2020. Tea tourism: beyond just a cup of tea. Features, Daily News, 25. Zhou, Q. et al. (2023) 'Tea culture tourism perception: A study on the harmony of importance and performance', Sustainability, 15(3), p. 2838. doi:10.3390/su15032838.

[26] Jolliffe, L. (2007) 'Chapter 1. connecting tea and tourism', Tea and Tourism, pp. 3–20. doi:10.21832/9781845410582-003.

[27] Xia, M., Zhang, Y. and Gu, R., 2023. Creative Tea Beverages as a New Tourism Attraction? Exploring Determinants of Tourists' Repurchase Intention Using Dual Process Theory. Sustainability, 15(13), p.10642.

[28] Gupta, V., Sajnani, M., Dixit, S.K. and Khanna, K., 2022. Foreign tourist's tea preferences and relevance to destination attraction in India. Tourism Recreation Research, 47(4), pp.428-442.

[29] Su, X. and Zhang, H., 2022. Tea drinking and the tastescapes of wellbeing in tourism. Tourism Geographies, 24(6-7), pp.1061-1081.

[30] Ranagalage, M., Wang, R., Gunarathna, M.H.J.P., Dissanayake, D.M.S.L.B., Murayama, Y. and Simwanda, M., 2019. Spatial forecasting of the landscape in rapidly urbanizing hill stations of South Asia: A case study of Nuwara Eliya, Sri Lanka (1996– 2037). Remote Sensing, 11(15), p.1743.

[31] Mohamed Ismail Hilal and Kaldeen Mohamed Mubarak. 2016b. International Tea Marketing and need for reviving Sri Lankan tea industry. Journal of Management 9, 1 (February 2016), 25.DOI:http://dx.doi.org/10.4038/jm.v9i1.7563

Appendix

Annexure 01 - Interview guide
I would like to express my appreciation for your participation and cooperation in this survey. This survey is conducted by H.Y.M.Sankalpama, an undergraduate student following a BSc Travel & Tourism Management Degree at SLTC Research University as a partial fulfillment of the requirement of the Degree. This interview prototiles was prepared as a tool to gather relevant data for the research under the aforementioned title and your kind co-operation in filling this questionnaire is important and highly appreciated. The data will be used anonymously and exclusively for scientific research purposes only and treated as strictly confidential.

Before getting the Sri Lankan Tea Tourism Experience what were your expectations about it?

What motivated you to choose a Sri Lankan tea tourism as a recreational activity in your vacation?

Are you satisfied with the experience?

[If yes / No to the above question] How would you describe your experience? Can you tell How did you feel? And emotions you have felt during the tea tourism experience you had?

What were the most memorable or surprising aspects of Sri Lankan tea tourism experience?

What do you see as the unique value of Sri Lankan authentic tea experience?

Do you think Sri Lankan tea tourism experience is different and has unique features compared to other countries?

Would you recommend the Sri Lankan tea tourism to others? Why?

Will you come back to Sri Lanka for getting a tea related tourism experience again?

What kind of suggestions do you have for improving the Sri Lankan tea tourism?

Annexure 02 - Themes and Codes

Themes and Codes

Expectations	Tourists' Satisfaction and Emotional Responses Positive Emotions: Sensory Experience: Cultural Appreciation: Interest in Process: Desire for Interaction: Health Perspective:
Motivations	Recommendation and reason
Satisfaction	
Memorable and Surprising Aspects of Sri Lankan Tea Tourism	
Unique Value	
Comparison with Other Countries	
Return Intentions	
Suggestions for Improvement	

Machine Learning, Artificial Intelligence and Robotics

Enhancing Stock Price Forecasting on the Colombo Stock Exchange with Cluster-Based Gated Recurrent Unit Architectures

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Abstract*— Deep learning algorithms like Gated Recurrent Unit (GRU) networks are increasingly used in financial forecasting, particularly for stock market prediction, due to their superiority in modeling non-linear interactions. GRUs simplify internal gating processes, allowing for more computationally efficient methods for capturing long-term dependencies, enabling accurate temporal modeling, and minimizing the vanishing gradient problem. This paper introduces a novel clustering-enhanced GRU model for stock price forecasting on the Colombo Stock Exchange (CSE), addressing shortcomings in existing approaches by employing clustering as a critical pre-processing step. By using clustering as a crucial pre-processing step, this work fills gaps in current methods by introducing a unique clustering-enhanced GRU model for stock price forecasting on the CSE. In contrast to earlier models, our approach optimizes clustering by taking into account the noise and volatility of financial data by utilizing a number of similarity metrics, including Euclidean distance (EUD), Dynamic Time Warping (DTW), and the Logistic Weighted Dynamic Time Warping (LWDTW). The distance matrices were computed using CSE daily closing stock price data. The accuracy of stock price projections was subsequently maximized by applying clustering-augmented GRU using the three previously mentioned similarity measurements. The GRU model with clustering augmentation and the GRU model without clustering were thoroughly compared. The results show that the GRU architecture with the LWDTW methodology performs better than other approaches in terms of efficiency and forecasting ability, with the lowest root mean square error (RMSE) value of 0.0189 and the greatest R^2 value of 0.9545. These findings show how better financial market decision-making can arise from using deep learning models and clustering approaches to assess CSE stock values more precisely.

Keywords—clustering, deep learning algorithms, distance computation, financial forecasting, internal gating process

I. INTRODUCTION

The stock market functions as a place for the exchange of shares or stocks of different companies. Due to the extremely complicated and volatile nature of the stock market, artificial intelligence (AI) technologies are becoming a growing trend for forecasting financial and economic time series [1]. Therefore, more research is urgently needed to better understand time series forecasting techniques, decision-making approaches, and our understanding of predictability in the face of these dynamic and unpredictable events. The conventional finance prediction framework has been built upon a number of ideal assumptions of financial theory, including risk-averse investor preferences, homogeneous investment beliefs, the lack of transaction costs, and unfettered access to risk-free assets. On the basis of these assumptions, forecasting techniques like portfolio sorts and linear regressions, such as Auto Regressive (AR), Auto Regressive Moving Average (ARMA), and Auto Regressive Integrated Moving Average (ARIMA) have been implemented extensively. In response to these difficulties, a prominent research trend in financial forecasting has been the use of deep-learning models [3].

The capacity to function without strict assumptions and with limited reliance on financial specialists is a significant benefit of using deep learning techniques in financial forecasting. Furthermore, deep learning models have the ability to automatically identify important patterns and high-level features in the incoming data. Thus, by utilizing deep learning, these models provide a possible means of resolving the drawbacks of conventional methods, thereby enabling enhanced prediction precision and insights in the financial field. For more precise temporal modeling, deep learning algorithms like GRU networks can be utilized. These algorithms are especially good at capturing long-term dependencies, managing sequential data effectively, and resolving issues like the vanishing gradient problem [4]. Compared to Long Short-Term Memory (LSTM) networks, GRUs have a simpler architecture with fewer parameters and an easier-to-use gating mechanism. Consequently, GRUs may finish a large number of tasks with similar outcomes while using fewer processing overhead and shorter training cycles. Moreover, GRUs are an excellent option for CSE stock price prediction when training data is scarce or processing speed is critical.

This study intends to improve GRU performance by using clustering algorithms—a preprocessing technique not yet investigated in this particular context—because the implementation of GRUs in stock price forecasting on the CSE has been limited. The main goals are to evaluate how clustering affects the accuracy of GRU predictions and to contrast different similarity metrics that are employed to optimize clustering for better forecasting results. Although earlier studies have shown that GRUs are useful for financial forecasting, there aren't many that apply GRUs to specialized markets like the CSE, especially when paired with clustering approaches. In addition to increasing forecast accuracy, the goal of this approach is to expand knowledge about the practical applications of cutting-edge AI techniques in emerging and niche financial markets. The results of this study may lead to the development of more advanced forecasting models that are more suited to manage the peculiarities and complexities of markets such as the CSE, hence facilitating more informed decision-making in the financial sector.

II. METHODOLOGY

Using historical stock prices from the CSE, this study examines trends in the Sri Lankan stock market from January 2006 to December 2018. After data cleansing and normalization, two benchmark methods: the DTW method and the EUD method were utilized, along with the novel LWDTW method for similarity computation to compute distance matrices. The selection of each approach was based on how well it handled the inherent volatility and noisy nature of financial data. Because DTW and LWDTW may take into consideration changes in time series data, they are superior to basic distance measurements like EUD in identifying trends in a range of market situations. Particularly, the LWDTW measure offers a new method that hasn't been widely used in stock forecasting by introducing a weighting mechanism that highlights the importance of particular return observations.

Next, in order to determine the optimum number of clusters and to group stocks with comparable price patterns, we employed k-means clustering [2]. We employed two widely used internal clustering evaluation metrics, the Davies-Bouldin Index (DBI) and the Dunn Index (DI), to examine the compactness and separateness of the generated clusters and to find the optimal number of clusters (k). By ensuring that the stocks inside each cluster shared strong similarities while being clearly distinct from those in other clusters, these criteria helped to improve the clustering process.

Once the optimum number of clusters was determined, the sample data was methodically split into three sets: training, validation, and testing, with a ratio of 10:2:1. This splitting provided guarantee that the model was trained efficiently, validated for parameter tuning, and tested for performance evaluation. Next, we created GRU-based forecasting models for each of the three similarity measures, with and without clustering enhancement.

The performance of the GRU models with and without clustering was then compared, and various evaluation metrics were used to do so: Mean Absolute Percentage Error (MAPE), Mean Absolute Error (MAE), Mean Square Error (MSE), Root Mean Square Error (RMSE), and R-squared Value (R^2). The potential advantages of using clustering techniques in GRU-based stock price forecasting on the CSE were highlighted by these measures, which offered a thorough evaluation of each model's predicted accuracy and efficacy.

III. RESULTS

In order to account for the size of the dataset, we evaluated internal clustering across a range of cluster counts (k trials, from 2 to 20). Based on the DI values, the LWDTW method consistently outperformed the EUD and DTW methods, confirming its utility in capturing essential financial trends .

TABLE I. DI AND DBI VALUES FOR DIFFERENT SIMILARITY MEASURES

	DI Value	**DBI Value**	***k* Value**
EUD	0.020	0.420	2
DTW	0.007	0.400	2
LWDTW	**0.700**	**0.090**	**2**

To be more precise, LWDTW formed the most optimal clusters at $k = 2$, as evidenced by the maximum DI value of 0.7 that was obtained.

And also, LWDTW exhibited superior clustering performance once more when comparing the DBI values. For $k = 2$, LWDTW outperformed DTW and EUD in producing discrete and cohesive clusters, as evidenced by its lowest DBI value (less than 0.1).

These findings confirm the usefulness of LWDTW in determining stock price trends and provide support for the $k = 2$ clusters in the prediction framework.

Then, we implemented with and without clustering upgraded frameworks and performed the performance comparison using $k = 2$ clusters.

By carefully evaluating the outcomes with and without clustering improved frameworks, we can clearly see that the clustering enhanced framework is better suited for stock price prediction than using no clustering framework at all. Moreover, GRU combined with LWDTW performs better than any other method in the clustering improved framework.

TABLE II. FORECASTING ACCURACY FOR WITHOUT CLUSTERING GRU MODEL

Performance Measure	**GRU Model**
MAE	0.0462
MAPE (%)	9.0502
MSE	0.0035
RMSE	0.0595
R^2	0.9122

TABLE III. TRAINING AND VALIDATION LOSSES IN FINAL EPOCH FOR NO CLUSTERING GRU MODEL

	Training Loss	**Validation Loss**
No clustering GRU model	0.0036	0.0020

TABLE IV. FORECASTING ACCURACY FOR CLUSTERING ENHANCED GRU MODEL

Performance Measures for Clustering Enhanced GRU Model	**Similarity Measure**		
	EUD	***DTW***	***LWDTW***
MAE	0.0219	0.0288	**0.0141**
MAPE (%)	3.1335	4.1563	**2.0317**
MSE	0.0007	0.0011	**0.0003**
RMSE	0.0268	0.0332	**0.0189**
R^2	0.9247	0.8845	**0.9545**

TABLE V. TRAINING AND VALIDATION LOSSES IN FINAL EPOCH FOR CLUSTERING ENHANCED GRU MODEL

	Similarity Measure	**Training Loss**	**Validation Loss**
Clustering enhanced GRU model	EUD	0.0008	0.0009
	DTW	0.0007	0.0017
	LWDTW	0.0009	0.0015

IV. CONCLUSION

In order to precisely forecast the dynamics of the Sri Lankan stock market, this work presents a clustering-enhanced prediction framework based on the GRU model. The methodology prioritizes accuracy and incorporates the novel LWDTW similarity metric, demonstrating the significance of individual stock price data and outperforming traditional benchmarks. This sophisticated clustering method, when paired with the GRU model, achieves previously unheard-of levels of clustering accuracy, greatly improving predictions for the Sri Lankan stock market. The LWDTW similarity metric is crucial for finding related stocks and has a big impact on clustering results, which produces extremely precise forecasts. Performance comparisons show that the clustering-enhanced GRU framework performs better than models without clustering, especially when it comes to capturing complex market trends. Effective learning and excellent generalization to new data were regularly demonstrated by the GRU model with clustering, which also consistently displayed lower training and validation losses. This equilibrium between validation and training losses strengthens the appropriateness of the GRU model for CSE stock price prediction. With the help of this revolutionary prediction technology, investors may now make well-informed decisions with increased confidence in the real world. It is crucial to understand that outside variables and the state of the economy can have an impact on how accurate stock market forecasts are. In order to ensure the framework's stability in a variety of market circumstances, future study should take into account real-time market changes and investigate how easily it can be modified to accommodate a wider range of factors when evaluating stock prices.

REFERENCES

[1] Hamza{\c{c}}ebi, C. a. (2009). Comparison of direct and iterative artificial neural network forecast approaches in multi-periodic time series forecasting. *Expert systems with applications*, pp.3839-3844

[2] Herman, E. a.-E. (2022). Cluster analysis with k-mean versus k-medoid in financial performance evaluation. Applied Sciences, 7985.

[3] Hiransha, M. a. (2018). NSE stock market prediction using deep-learning models. *Procedia computer science*, pp.1351-1362.

Comparative Analysis of BER Performance in UAV-assisted THz Communication Systems with Different Modulation Schemes

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***Abstract*—This paper presents a detailed comparison of bit error rate (BER) performance for three modulation schemes—Pulse Amplitude Modulation (PAM), Quadrature Am- plitude Modulation (QAM), and Chirp Spread Spectrum Mod- ulation (CSSM)—in the context of UAV-assisted terahertz (THz) communication systems. As THz communication gains traction for its potential to support ultra-high data rates, understanding the error performance of various modulation techniques is essential for optimizing system design. This study simulates and analyzes the BER performance of PAM, QAM, and CSSM under various signal-to-noise ratio (SNR) conditions, aiming to identify the trade-offs in reliability and efficiency for each scheme. The results indicate that CSSM exhibits superior resilience under noisy and fluctuating conditions, making it the most robust choice for UAV-assisted THz communication. In contrast, QAM performs moderately well at high SNR levels but is less effective in low-SNR environments, while PAM requires high SNR for reliable performance. These findings offer valuable guidance for selecting suitable modulation schemes in THz communication systems, especially for UAV applications.**

***Index Terms*—THz communication, BER, PAM, QAM, Chirp Spread Spectrum Modulation (CSSM)**

I. Introduction

The growing demand for ultra-high data rates and bandwidth efficiency has positioned terahertz (THz) communication as a promising solution for future wireless technologies, including 6G and the Internet of Things (IoT) [1], [2]. The integration of Unmanned Aerial Vehicles (UAVs) in communication systems enhances network flexibility and coverage, particularly when combined with THz communication, enabling UAVs to serve as mobile base stations and relay nodes [3], [4].

While several studies have explored UAV-assisted communi- cations using a variety of technologies [5]–[17], fewer have fo- cused on the comparative performance of modulation schemes in UAV-assisted THz systems. For instance, [6] demonstrated that THz and visible light communication (VLC) systems outperform Free-Space Optics (FSO) and Radio-Frequency

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(RF) communication under certain conditions, highlighting the potential of hybrid systems in UAV-assisted networks.

In addition, research has shown that UAV networks can be optimized using advanced technologies, such as machine learning and innovative network architectures [8]. These ad- vancements are crucial for enhancing data throughput and reducing bit error rate (BER), particularly in dynamic THz communication environments.

This paper compares the BER performance of three modula- tion schemes—Pulse Amplitude Modulation (PAM), Quadra- ture Amplitude Modulation (QAM), and Chirp Spread Spec- trum Modulation (CSSM)—in UAV-assisted THz systems. Unlike prior studies on UAV-assisted THz-VLC systems, this work addresses the gap in literature regarding a comprehensive analysis of modulation schemes. By evaluating BER under varying SNR conditions, we aim to offer valuable insights into the trade-offs between reliability and efficiency in THz communication, following a similar approach to [18].

II. System Model

The proposed system model as illustrated by Fig. 1, consists of a UAV equipped with a camera for surveillance, hovering stationary above a house to transmit high-resolution video footage using THz communication. This configuration facil- itates a consistent line-of-sight (LOS) communication link between the UAV and the receiving unit in the house, allowing for real-time video streaming with minimal latency. Although the UAV remains stationary, potential misalignment effects due to environmental factors may still impact the communication quality.

A. Channel Model

The gain of the THz channel is modeled as:

$$G_{THz} = g_p \cdot g_a \cdot g_m, \quad (1)$$

where g_p, g_a, and g_m represent the free-space path loss, molecular absorption loss, and misalignment loss, respectively. The free-space path loss g_p is based on the Friis equation, while molecular absorption loss g_a is modeled using an

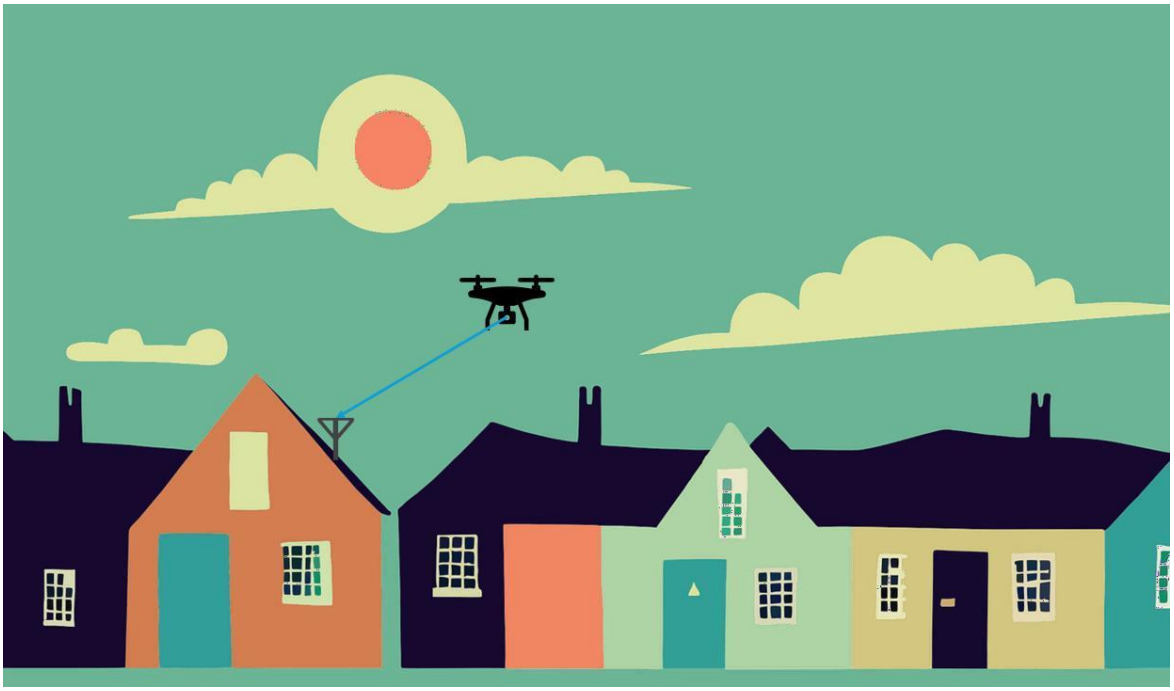

Fig. 1. The System Model.

absorption coefficient $\kappa a(f)$. Misalignment loss gm is derived from beam misalignment and approximated using $gm(s)$ with its PDF expressed as:

$$f_{gm}(y) = \frac{\eta^2}{B_0^{\eta^2}} y^{\eta^2 - 1}, \quad 0 \le y \le B_0,$$

where η relates the beam width to the pointing error.

III. Simulation Results

The simulation is conducted across a range of signal-to-noise ratio (SNR) values, specifically from 0 dB to 50 dB in increments of 5 dB, to observe the BER performance across low to high SNR conditions. The primary noise considered is thermal noise, which is prevalent in THz communica- tion systems due to the high-frequency band utilized. Addi- tional environmental factors affecting the THz channel include molecular absorption and potential misalignment loss caused by UAV movement and atmospheric disturbances. The UAV, equipped with THz communication modules, is simulated to hover at a fixed altitude, ensuring a consistent line-of-sight (LOS) link with the ground receiver. This setup aims to replicate a realistic scenario where the UAV provides stable THz communication under varying SNR conditions, taking into account the environmental challenges intrinsic to THz frequencies.

QAM, represented by the red curve, shows moderate per- formance with the BER decreasing as the SNR increases, achieving a BER below 10^{-5} at around 40 dB. While it offers

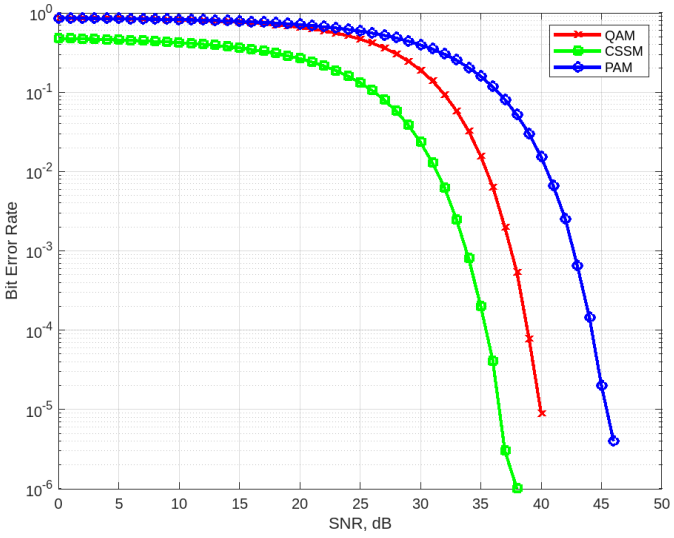

Fig. 2. Comparison of BER performance for QAM, CSSM and PAM modulation schemes

a balance between spectral efficiency and BER, it struggles under low SNR conditions, making it more suitable for short-distance or stable line-of-sight communication in UAV-assisted THz systems.

CSSM, shown by the green curve, delivers the best overall performance, achieving a BER below 10^{-5} at 37 dB. Its resilience to noise and adaptability in dynamic environments make it ideal for UAV-assisted THz communication, especially in varying SNR conditions and mobile scenarios.

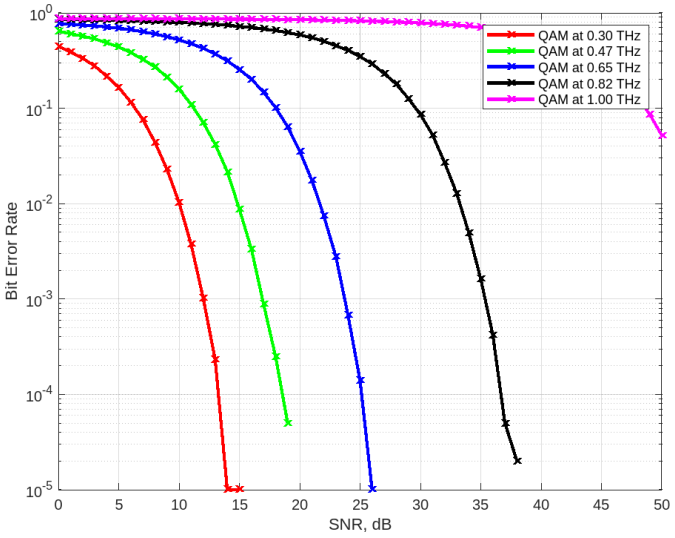

Fig. 3. Comparison of BER performance for QAM under varying frequencies

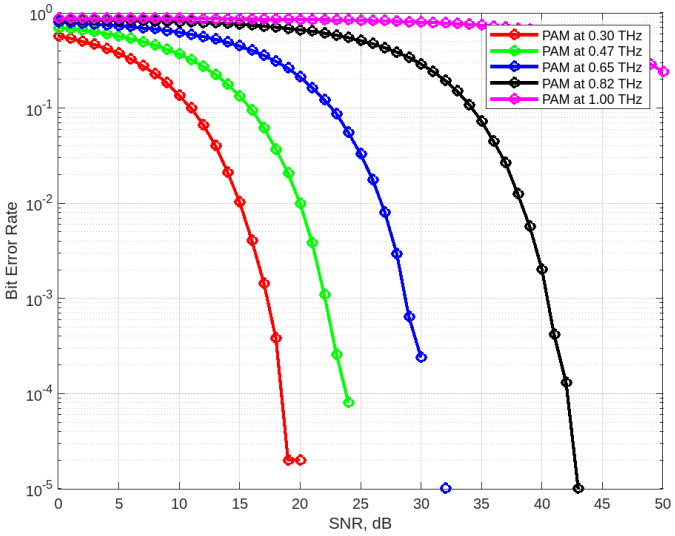

Fig. 4. Comparison of BER performance for PAM under varying frequencies

PAM, represented by the blue curve, provides the poorest performance, requiring an SNR of 45 dB to reach a BER below 10^{-5}. Due to its high susceptibility to noise, PAM is less viable for THz communication unless restricted by system constraints such as short-range, high-SNR applications.

The performance differences among these schemes stem from the THz band's susceptibility to free-space path loss and atmospheric absorption. CSSM's spread-spectrum technique mitigates these issues, excelling in fluctuating UAV channels, while QAM offers high spectral efficiency but is more prone to noise, and PAM lacks error-correction capabilities.

The BER performance comparison for QAM, CSSM, and PAM modulation schemes across different THz frequencies are illustrated in Fig. 3, Fig. 5, and Fig. 4. QAM, as ob- served, performs well at lower frequencies (0.30 THz to 0.65

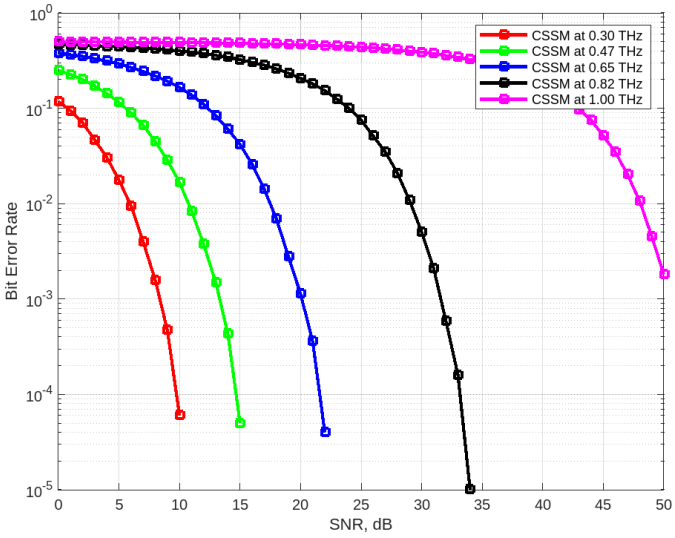

Fig. 5. Comparison of BER performance for CSSM under varying frequencies

THz), achieving a BER below 10^{-5} at moderate SNR levels. However, as the frequency increases (above 0.82 THz), its performance degrades, requiring significantly higher SNR val- ues to maintain acceptable BER levels. This indicates QAM's sensitivity to high-frequency THz channels, making it suitable mainly for short-range or stable link conditions.

CSSM, on the other hand, demonstrates superior performance across the entire frequency range, with notably low BER values even at higher frequencies (up to 1.00 THz) and lower SNR. This highlights CSSM's robustness in challenging environments, such as UAV-assisted communication systems, where the channel conditions may fluctuate due to mobility and environmental factors.

PAM consistently shows the poorest performance across all frequencies, requiring significantly higher SNR values to achieve acceptable BER levels. Its vulnerability to amplitude- related noise and distortions makes it unsuitable for THz communication, particularly in dynamic environments.

While QAM balances spectral efficiency and performance, it demonstrates higher susceptibility to noise, especially in low-SNR scenarios. This susceptibility arises from the mod- ulation's sensitivity to amplitude and phase errors, which are magnified in the THz band where free-space path loss and atmospheric attenuation are significant. Consequently, QAM is most suitable for stable, high-SNR conditions and shorter-range applications in UAV-assisted systems. CSSM outperforms the other schemes in robustness, achieving the lowest BER across varying SNR conditions. This resilience is attributed to its spread-spectrum approach, which enhances noise immunity and adaptability in dynamic environments. The THz band's vulnerability to absorption and misalignment loss is mitigated by CSSM's wide bandwidth usage, making it ideal for UAV applications in mobile or noisy environments. PAM's performance is the lowest among the schemes, as it requires a significantly higher SNR to achieve acceptable

BER levels. Its high susceptibility to amplitude noise makes PAM less viable in THz communication, especially where the environment is prone to rapid changes in signal conditions. Although simpler in design, PAM's lack of spread-spectrum benefits limits its application to short-range or high-SNR scenarios within UAV-assisted systems.

CSSM emerges as the most resilient and efficient modulation scheme for UAV-assisted THz communication, especially in dynamic and noise-prone conditions. QAM can be con- sidered under favorable, stable conditions, while PAM is not recommended unless in short-range, high-SNR scenarios.

IV. Conclusion

This study provides an in-depth analysis of the BER performance of modulation schemes, including PAM, QAM, and CSSM, in UAV-assisted THz communication systems. The results indicate that while QAM strikes a balance between spectral efficiency and performance, it falters at low SNR. CSSM proves to be the most robust, showing strong resistance to noise and misalignment, making it ideal for dynamic UAV environments. PAM, though simpler, underperforms in noisy conditions, limiting its broader applicability. The findings highlight the critical role of choosing modulation schemes based on specific environmental conditions, offering valuable insights for improving UAV-assisted THz communication sys- tems in various applications.

References

[1] D. Serghiou, M. Khalily, T. W. Brown, and R. Tafazolli, ―Terahertz chan- nel propagation phenomena, measurement techniques and modeling for 6g wireless communication applications: A survey, open challenges and future research directions,‖ *IEEE Communications Surveys & Tutorials*, vol. 24, no. 4, pp. 1957–1996, 2022.

[2] I. F. Akyildiz, A. Kak, and S. Nie, ―6g and beyond: The future of wireless communications systems,‖ *IEEE access*, vol. 8, pp. 133 995– 134 030, 2020.

[3] Y. Zeng, R. Zhang, and T. J. Lim, ―Wireless communications with unmanned aerial vehicles: Opportunities and challenges,‖ *IEEE Com- munications magazine*, vol. 54, no. 5, pp. 36–42, 2016.

[4] A. Masaracchia, Y. Li, K. K. Nguyen, C. Yin, S. R. Khosravirad, D. B. Da Costa, and T. Q. Duong, ―Uav-enabled ultra-reliable low-latency communications for 6g: A comprehensive survey,‖ *IEEE access*, vol. 9, pp. 137 338–137 352, 2021.

[5] A. Patil, M. P, and D. N. K. Jayakody, ―Performance of uav networks over the ocean: A perspective towards connected ocean,‖ *Wireless Personal Communications*, pp. 1–20, 2024.

[6] H. Rajahrajasingh and D. N. K. Jayakody, ―Unmanned aerial vehicle- assisted terahertz–visible light communication systems: An in-depth performance analysis,‖ *Sensors*, vol. 24, no. 13, p. 4080, 2024.

[7] V. Sharma, D. N. K. Jayakody, and K. Srinivasan, ―On the positioning likelihood of uavs in 5g networks,‖ *Physical Communication*, vol. 31, pp. 1–9, 2018.

[8] A. Sharma, P. Vanjani, N. Paliwal, C. M. W. Basnayaka, D. N. K. Jayakody, H.-C. Wang, and P. Muthuchidambaranathan, ―Communi- cation and networking technologies for uavs: A survey,‖ *Journal of Network and Computer Applications*, vol. 168, p. 102739, 2020.

[9] H. Rajahrajasingh, D. N. K. Jayakody, P. Muthuchidambaranathan, and R. Dinis, ―Hybrid vlc systems with terahertz communication: A perfor- mance analysis,‖ in *2024 IEEE 100th Vehicular Technology Conference (VTC2024-Fall)*, 2024.

[10] D. N. K. Jayakody, T. D. P. Perera, A. Ghrayeb, and M. O. Hasna, ―Self- energized uav-assisted scheme for cooperative wireless relay networks,‖ *IEEE Transactions on Vehicular Technology*, vol. 69, no. 1, pp. 578–592, 2019.

[11] M. F. Ali, D. N. K. Jayakody, and P. Muthuchidambaranathan, ―Rev- olutionizing firefighting: Uav-based optical communication systems for wildfires,‖ in *Photonics*, vol. 11, no. 7. MDPI, 2024, p. 656.

[12] C. M. W. Basnayaka, D. N. K. Jayakody, and M. Beko, ―Freshness-in- air: An aoi-inspired uav-assisted wireless sensor networks,‖ *ICT Express*, 2024.

[13] A. Jeganathan, B. Dhayabaran, D. N. K. Jayakody, S. A. R. Don, and P. Muthuchidambaranathan, ―An intelligent age of information based self-energized uav-assisted wireless communication system,‖ *IET Communications*, vol. 17, no. 19, pp. 2141–2151, 2023.

[14] A. Gunasekar, L. B. Kumar, P. Krishnan, R. Natarajan, and D. N. K. Jayakody, ―All-optical uav-based triple-hop fso-fso-vlc cooperative sys- tem for high-speed broadband internet access in high-speed trains,‖ *IEEE Access*, 2023.

[15] H. Hydher, D. N. K. Jayakody, K. T. Hemachandra, and T. Sama-rasinghe, ―Uav deployment for data collection in energy constrained wsn system,‖ in *IEEE INFOCOM 2022-IEEE Conference on Computer Communications Workshops (INFOCOM WKSHPS)*. IEEE, 2022, pp. 1–6.

[16] H. Hydher, D. N. K. Jayakody, and S. Panic, ―Maximizing the latency fairness in uav-assisted mec system,‖ *IET Intelligent Transport Systems*, vol. 16, no. 4, pp. 434–444, 2022.

[17] T. D. P. Perera and D. N. K. Jayakody, ―Aoi-driven swipt-enabled uav trajectory optimization for two-way relaying,‖ *Transactions on Emerging Telecommunications Technologies*, vol. 35, no. 1, p. e4910, 2024.

[18] S. S. Morapitiya, T. Leelarathna, and D. N. K. Jayakody, ―Ber analysis in ps-slipt architecture using different modulation schemes,‖ 2023.

Mathematics, Material Science and Technology

A Novel Factorization Method Using Continued Fractions

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***Abstract*— The study of continued fractions is a significant area of mathematics with diverse applications, particularly in the field of factorization. Continued fractions can be used to approximate irrational numbers and are integral to algorithms for factoring integers. In this study, we present a novel method for factoring large integers that utilize generalized continued fractions to improve efficient factorization. Additionally, we introduce several theoretical statements about generalized continued fractions and demonstrate their application within the proposed factorization algorithm. Using this algorithm, we successfully factor a large integer into two prime numbers, whose product constitutes the original large number. Our findings suggest that this method is a highly effective tool in number theory, cryptography, and computational mathematics.**

Keywords—continued fractions, generalized continued fractions, integer factorization, prime numbers

I. INTRODUCTION

Integer factorization is the decomposition of a positive integer into a product of integers. The study of integer factorization has a very long history and the studies have a wide range of applications. Although there are many different integer factorization algorithms to choose from, we will focus on integer factorization method by using continued fractions called as CFRAC algorithm. First, CFRAC algorithm was founded by D. H. Lehmer and R. E. Powers in 1931, and developed as a computer algorithm by Michael A. Morrison and John Brillhart in 1975. The CFRAC algorithm has the ability to factor integers that are fifty digits or less. In the present study, we will describe a method of factoring large integers by using generalized continued fractions, it is a generalization of regular continued fractions in canonical form. Before we start looking at this algorithm, we will explore the theoretical foundations of generalized continued fractions.

Definition 1.1.
A generalized continued fraction is an expression of the form,

$$x = b_0 + \cfrac{a_1}{b_1 + \cfrac{a_2}{b_2 + \cfrac{a_3}{b_3 + \cfrac{a_4}{b_4 + \ddots}}}} \#(1)$$

where $a_k (k > 0)$are the partial numerators, b_k $(k > 0)$ are the partial denominators, and the leading term b_0 is called the integer part of the continued fraction.
Generalized continued fractions may also be written in the forms

$$x = b_0 + \frac{a_1}{b_1 +}\frac{a_2}{b_2 +}\ldots \#(2)$$

or

$$x = b_0 + \sum_{k=1}^{\infty} \frac{a_k}{b_k} \#(3)$$

For any k, a natural number, k th convergent of (1) is given by,

$$C_k = \frac{A_k}{B_k} = b_0 + \frac{a_1}{b_1 +}\frac{a_2}{b_2 +}\ldots \frac{a_k}{+b_k} \#(4)$$

Definition 1.2.
The partial denominators of the fractions' successive convergents are related by the fundamental recurrence formulas:

$$A_k = b_k A_{k-1} + a_k A_{k-2} \#(5)$$

$$B_k = b_k B_{k-1} + a_k B_{k-2} \#(6)$$

for $k \geq 1$ with initial values,

$A_{-1} = 1$ $\qquad$ $A_0 = b_0$

$B_{-1} = 0$ $\qquad$ $B_0 = 1$

Theorem 1.1.
Suppose N is a positive integer which is not a perfect square with convergent $\frac{A_k}{B_k}$.Then,

$$A_k^2 > 2\sqrt{N} \pmod N \#(7)$$

This theorem is one of the reasons why this algorithm works.[6]

Theorem 1.2.
If N is a composite integer, $X, Y \in \mathbb{Z}$ and $X^2 \equiv Y^2 \pmod N$, but $X \not\equiv \pm Y \pmod N$, then $\gcd(X - Y, N)$ and $\gcd(X + Y, N)$ are proper factors of N. [2]

The n^{th} root of any positive number z^m can be expressed by restating $z = x^n +$, resulting in,

$$\sqrt[n]{z^m} = \sqrt[n]{(x^n + y)^m}$$

$$= x^m + \cfrac{my}{nx^{n-m} + \cfrac{(n-m)y}{2x^m + \cfrac{(n+m)}{3nx^{n-m} + \cfrac{(2n-m)y}{2x^m + \ddots}}}} \quad \#(8)$$

The square root of z is a special case with $m = 1$ and $n = 2$.
So,

$$\sqrt{z} = \sqrt{x^2 + y} = x + \cfrac{y}{2x + \cfrac{y}{2x + \cfrac{3y}{6x + \cfrac{3y}{2x + \ddots}}}} \quad \#(9)$$

which can be simplified as,

$$\sqrt{z} = \sqrt{x^2 + y} = x + \cfrac{y}{2x + \cfrac{y}{2x + \cfrac{y}{2x + \cfrac{y}{2x + \ddots}}}} \quad \#(10)$$

II. METHODOLOGY

To factor a number (> 1), the first step is to determine whether N is a perfect square or a prime power. If N is a perfect square, we can find the factors by getting the square root of N. In the case of N being a prime power, it can be expressed as $N = p^k$, where p is a prime number and k is a positive integer. Then, assess whether N is odd or even. If N is even, repeatedly factor out 2 until the number is odd. Hence, we can write N as $N = 2^k q$, where k is a positive integer and q is odd. Therefore, we consider N is an odd, composite integer that is not a perfect square or prime power.

We start by expanding $\sqrt{N}$ as,

$$\sqrt{N} = \sqrt{x^2 + y} = x + \cfrac{y}{2x + \cfrac{y}{2x + \cfrac{y}{2x + \cfrac{y}{2x + \ddots}}}} \quad \#(11)$$

where x, y be positive integers, x be the largest integer less than $\sqrt{N}$ and y is not a multiple of x. If y is a multiple of x, say $y = k$, then we can write

$$\sqrt{N} = \sqrt{x^2 + kx} = \sqrt{(x + k)} \ \#(12)$$

Hence, we can factor N as, $N = (x + k)$.

Therefore, we consider y as not a multiple of x. By looking at (5), we can define A_k as the numerator of the k th convergent and that A_k is dependent upon $a_k, b_k, A_{k-1}, A_{k-2}$. These A_k terms represent the possible values for X and thus A_k^2 modulo N represents the possible values for Y^2, from which we can computer A_k term of the k th convergent $\frac{A_k}{B_k}$ of the generalized continued fraction expansion of $\sqrt{N}$.
By considering the expressions (1) and (11), we obtain $a_k = y$, $b_k = 2x$ for all $k = 1,2,3, \ldots$ and $b_0 = x$. Next, we construct a table with a_k, b_k, $A_k \pmod N$ and $A_k^2 \pmod N$ terms.
Note that,

$$A \pmod N \neq \sqrt{A^2 \pmod N} \#(13)$$

For the corresponding k value that satisfies the previous steps, let

$$X = A \pmod N \ \#(14)$$

then we obtain

$$X^2 \equiv Y^2 \pmod N \ \#$$

So,

$$Y^2 = A_k^2 \pmod N \ \#(15)$$

If $X \equiv \pmod N$, then, a new $A^2 \pmod N$ value needs to be found. Otherwise, we can find the factors of N.

If X G $\pmod N$ and $X + Y \neq N$, then we can get factors of N by calculating,

$$\gcd(X + Y, N)$$

and

$$\gcd(X - Y, N).$$

III. RESULTS AND DISCUSSION

Consider an example to find the factors of an integer.

Let $N = 10123$ and we can find the generalized continued expansion of $\sqrt{N}$ in the form,

$$\sqrt{N} = \sqrt{10123} = \sqrt{100^2 + 123}$$

$$= 100 + \cfrac{123}{200 + \cfrac{123}{200 + \cfrac{123}{200 + \cfrac{123}{200 + \ddots}}}}$$

From the given expression we can deduce that $x = 100$ and $y = 123$. Thus, we obtain $a_k = 123$, $b_k = 200$ for all $k = 1,2,3, \ldots$ with $b_0 = 100$.
Hence, we can write A_k term as,

$$A_k = 200A_{k-1} + 123A_{k-2} \text{ for } k = 1,2,3 \ldots$$
$$A_0 = 100$$
$$A_{-1} = 1$$

We will compute the $A(\text{mod } N)$ and $A^2_k(\text{mod } N)$ values until the value of $A^2_k(\text{mod } N)$ is conformed as a perfect square.

We construct a table as follows.

TABLE I. CONTINUED FRACTION FOR $\sqrt{10123}$

k	a_k	b_k	$A_k(\text{mod } N)$	$A^2_k(\text{mod } N)$
0	-	100	100	10000
1	123	200	10000	5006
2	123	200	7946	1765
3	123	200	5006	5611
4	123	200	4573	8334
5	123	200	1765	7464
6	123	200	4409	3121
7	123	200	5611	791
8	123	200	4335	3937
9	123	200	8334	1653
10	123	200	3314	9264
11	123	200	7464	4427
12	123	200	7421	2121
13	123	200	3121	2315
14	123	200	8410	8822
15	123	200	791	8178
16	123	200	8239	6406
17	123	200	3937	1656
18	123	200	9026	8895
19	123	200	1653	9322
20	123	200	3332	7416
21	123	200	9264	9025

Examining the values in the table, we observe that when $k = 21$, the corresponding $A^2_k(\text{mod } N)$ value yields a perfect square.
So, when $k = 21$,

$$A^2_k(\text{mod } N) = 9025 = (\pm 95)^2$$

Then, we will verify whether $A(\text{mod } N) \neq \sqrt{A^2_k(\text{mod } N)}$
Since, $A(\text{mod } N) = 9264$,

$$A_k(\text{mod } N) \neq \sqrt{A^2_k(\text{mod } N)} \quad \text{when } k = 21$$

Let

$$X = 9264 \ (\text{mod } 10123)$$

and

$$Y^2 = 9025 = (\pm 95)^2 \ (\text{mod } 10123)$$

This implies $Y = \pm 95 \ (\text{mod } 10123)$
Also, we can observe that $X \neq Y(\text{mod } 10123)$ and $X + Y \neq 10123$

Therefore, we can find the factors of $N = 10123$ by calculating $\gcd(X + Y, N)$ and $\gcd(X - Y, N)$.

$$\begin{aligned}\gcd(X + Y, N) &= \gcd(9264 + 95, 10123)\\ &= \gcd(9359, 10123)\\ &= 191\end{aligned}$$

and

$$\begin{aligned}\gcd(X - Y, N) &= \gcd(9264 - 95, 10123)\\ &= \gcd(9169, 10123)\\ &= 53\end{aligned}$$

Therefore,

$$N = 10123 = 191 \times 53.$$

Recall that we are trying to solve $X^2 \equiv Y^2(\text{mod } N)$ where $X \neq (\text{mod } 10123)$. In this algorithm, we utilize the numerators of the convergent to represent values for X .The numerator of the convergent squared is going to be greater than $-2\sqrt{N}$ and less than $2\sqrt{N}$ according to the theorem 1.1. This bounding is significant, because this will in turn create smaller prime. We could have to attempt to determine the prime factorization of a large number if we did not have this constraint. In general, this is an issue because factoring a large number is quite challenging. Hence, this simplification is the key to the overall effectiveness of the factorization process.

IV. CONCLUSION

In this research, we developed a factorization algorithm based on generalized continued fractions. As an application, this can be utilized to effectively decrypt messages encoded using cryptographic algorithms such as RSA encryption. This algorithm not only offers a practical and straightforward approach for small-scale cases but is also designed to be easily understood and implemented. For future enhancements, we plan to implement the algorithm in a programming language and conduct comprehensive testing across a diverse range of integers, from small to large. Furthermore, we will compare the efficiency of our algorithm with other established factorization techniques, thereby contributing valuable insights to the field of cryptography.

REFERENCES

[1] D. M. Burton, "Elementary Number Theory", 7th Edition, McGraw-Hill, 2010.
[2] J. P. Hii, "Continued fraction factorization algorithm", Cross-section, (XIII), ANU Student Journals, 2022.
[3] K. H. Rosen, "Elementary Number Theory", Pearson Education, London, 2011.
[4] M. Anselm and S. H. Weintraub, "A generalization of continued fractions", Journal of Number Theory 131(12), pp.2442-2460, 2011.
[5] M. A.. Morrison and J. Brillhart, "A method of factoring and factorization of F7," Mathematical of computation, American Mathematical Society, 1975.
[6] M. S. Ferey, "Factoring large numbers with continued fractions" (University of Redlands), 2009.
[7] S. Farhangi, "What is the continued fraction factoring method? (Ohio State University), 2018.
[8] S. Kadyrov, F. Mashurov, "Generalized continued fraction expansions for π and e", Journal of Discrete Mathematical Scienc and Cryptography, 24(6), pp.1809-1819, 2021.

Optimizing Nitrogen Doping in Graphene Oxide for Superior WS_2-based Hydrogen Evolution Catalysts

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Abstract*— The electrocatalytic performance of WS_2 in the hydrogen evolution reaction (HER) can be significantly improved by employing graphene oxide (GO) as the substrate. Incorporating non-metals (such as N, S, P, etc.) into graphene oxide (GO) sheets has the potential to enhance the electrocatalytic activity even further. In this study, the initial step involved tuning GO through the doping of varying amounts of nitrogen (25, 35, and 45 w/w%), introduced from urea. Subsequently, WS_2 was synthesized on nitrogen-doped reduced graphene oxide (NrGO) to create the WS_2-NrGO nanocomposite using a two-step hydrothermal process. The formation of tuned NrGO was confirmed through FTIR, Raman, and SEM imaging techniques. The FTIR spectra validated the incorporation of nitrogen into GO, evidenced by the presence of pyridinic and pyrrolic nitrogen in all three NrGOs. Additionally, the intensity of these bonds increased with the rising amount of nitrogen doping. Raman analysis indicated that NrGOs exhibit a lower ID/IG ratio in comparison to GO, implying an enhancement in the size of C sp^2 atom clusters due to the simultaneous reduction of GO. Voltammetry was employed to assess the electrocatalytic performance of the WS_2-NrGO nanocomposite. The polarization curve shows that WS_2-35%NrGO exhibits the lowest overpotential of -382.65 mV at a current density of -10 mA cm^{-2}, along with the lowest Tafel slope of 105.01 mV dec^{-1}. WS_2-35%NrGO exhibits the highest electrochemical active surface area (ECSA) of 63.5 cm^2. The findings suggest that an optimal nitrogen doping level of 35% into GO significantly improves the electrocatalytic activity for hydrogen evolution reactions.

Keywords*— Nitrogen doped reduced graphene oxide, Tungsten disulfide, Electrocatalyst, Hydrogen evolution reaction, Water splitting

I. INTRODUCTION

With the increasing conventional energy crisis and the growing issue of destruction of the environment, it has become widely agreed upon that the sustainable growth of human society requires a transformation of the energy structure and an increase in the share of renewable energy [1]. Hydrogen demonstrates significant promise as an optimal energy carrier for a sustainable energy economy, attributed to its high energy density and environmentally friendly production methods [2]. For hydrogen production, the electrocatalytic splitting of water by the hydrogen evolution reaction (HER) is a crucial process with a high energy conversion efficiency [2]. The hydrogen evolution reaction (HER) is predominantly conducted with rare and costly Pt catalysts, which need to be substituted with accessible nonprecious metal-based materials to enhance the economic feasibility of water splitting. Compounds like MoS_2, $MoSe_2$, WS_2, WSe_2, and 3d transition metals (TMs) have been extensively examined as potential alternatives to Pt-based catalysts for a long time [3]. Among these semiconducting materials, MoS_2 and WS_2, which exhibit a hexagonal P63/mmc structure, are the two typical compounds attracting significant attention due to their notable band gap. This characteristic imparts unique properties, such as a large surface area and a high density of active sites along the edges, enabling their use in various applications, particularly in electrochemical reactions such as HER [4].

Nonetheless, the efficacy of XS_2-based materials (X = Mo, W) in hydrogen evolution reaction remains inadequate when compared to platinum, due to several primary factors; only the edge sites of 2D XS_2 exhibit favorable catalytic activity, in contrast to the basal planes, and the inherently low conductivity hinders electron transfer and diminishes the efficiency for HER. A hybrid structure is essential for improving electrical conductivity, ensuring output stability, and extending lifespan. Consequently, nanostructures of MoS_2 and WS_2 were synthesized using a range of matrices, including rGO, CNT, metal particles/metal foil, oxides, and sulfides, as well as conducting polymers, to enhance their stability and electron transfer efficiency. Many prior studies have presented that carbon materials enhance the catalytic activity of MoS_2 and WS_2, due to their distinct physicochemical properties [5]

This study involved doping nitrogen into graphene oxide (GO) at various weight percentages (approximately 25%, 35%, and 45%) to synthesize WS_2 on N-doped reduced graphene oxide. This approach presents several advantages compared to undoped reduced graphene oxide, including enhanced electronic properties, increased active sites, tunable surface chemistry, improved catalytic synergy, and greater chemical stability. The FTIR studies and Raman spectra of NrGO confirmed the presence of nitrogen-carbon bonds in graphene oxide (GO). The SEM images of WS_2/NrGO confirm the growth of WS_2 on nitrogen-doped graphene oxide, while the Raman spectra illustrate the presence of the corresponding peaks of the material. The electrochemical findings indicated that by adjusting the nitrogen doping levels in graphene oxide, one could modulate both the quantity and edge length of WS_2 per area of nitrogen-doped reduced graphene oxide sheets. Notably, WS_2-35%NrGO demonstrated better electrocatalytic performance for hydrogen evolution reaction (HER).

II. METHODOLOGY

Synthesis of Nitrogen-doped graphene oxide :

Nitrogen doped graphene oxide was prepared hydrothermally following a previously reported method with some modifications. 25 mg of graphene oxide (GO) which was prepared by the Hummer's method was dispersed in 25 mL DI water by ultrasonication for 10 minutes. Then, 28.88 mg urea was added to the GO suspension and stirred for 1 hour. After, the solution was transferred to a 25 mL Teflon-lined autoclave and heated in an electric oven at 180 for 12 hours. The black product, 25% nitrogen doped-rG O, was collected and washed with several times with DI water and ethanol, respectively, and dried in a vacuum oven at 70 for overnight. 35% and 45% NrGO were synthesized i n the similar way but the addition of amount of urea was varied.

Synthesis of WS2@Nitrogen-doped graphene oxide :

WS_2@N-rGO was synthesized hydrothermally by the following protocol. First, 50 mg of NrGO was dispersed in 25 mL of DI water by the ultrasonication of 15 minutes. Then, 66.5 mg of $Na_2WO_4.2H_2O$, 61.4 mg of CH_4N_2S and 28.6 mg of $NH_2OH.HCl$ were dissolved in 25 mL of NrGO suspension (WS_2:NrGO=1:1; by weight ratio) using magnetic stirring for 4 hours at the room temperature. The pH of the mixture was maintained at 6 by adding a few drops of 2M NH_4OH. After that, the solution was transferred to a 25 mL Teflon-lined autoclave and heated in an electric oven at 180 for 12 hours. Finally, the black color product WS_2-NrGO , was collected and washed several times with DI water and ethanol, respectively, and dried in a vacuum oven at 70 for overnight.

Characterization :

Scanning Electron Microscope (SEM) was used to investigate the morphology of the samples. Raman spectrometry (RS) measurements were taken using the Renishaw Invia Reflex Raman microscopy system. Fourier Transform Infrared Spectroscopy (FTIR) analysis was aimed to identify the functional groups present in the material.

Electrochemical measurements :

Electrochemical measurements were performed in a typical three electrode system. Ag|AgCl and Pt wire were used as the reference electrode and counter electrode respectively. The working electrode utilized in the experiment was a glassy carbon electrode (GCE) with a 3 mm diameter, which was coated with a thin catalyst coating. Typically, 5 mg of sample and 5 μL of Nafion solution (5 wt%) were dispersed in 1 mL of water-ethanol solution (4:1 v/v) by sonication for 30 min to form a homogeneous ink. Then 5 μL of the ink was drop-cast onto a surface of GCE and dried at room temperature. All electrochemical measurements were made using a 0.5 M H_2SO_4 electrolyte after deaerated the solution with N_2 gas for 30 min. Linear sweep voltammetry (LSV) with a scan rate of 5 mV/s was conducted at room temperature. Cyclic voltammetry (CV) at different scan rates; 20, 40, 60, 80, 100, 120, 140, 160 mV/s were performed. All measured potentials (vs Ag|AgCl) were converted to the RHE according to the Nernst equation: $E_{RHE} = E_{Ag|AgCl} + 0.210 + 0.059^{*}pH$ [5]

III. RESULTS AND DISCUSSION

The chemical structures of GO, 25%NrGO, 35%NrGO, and 45%NrGO samples were characterized using FTIR, as illustrated in Fig. 1(a) and Fig. 1(b). GO sheets contain a variety of oxygen-containing groups, including hydroxyl (-OH), ketone (C=O), epoxy (C-O-C), and carboxyl (COOH) groups. FTIR bands were observed at 1048, 1220, 1400, 1630, and 1730 cm^{-1} for GO (Fig. 1(a)). The bands identified here relate to C-O stretching, C-O-C/C-OH stretching, O-H deformation vibration, skeletal vibrations (aromatic C=C, sp^2), and C=O carbonyl stretching. A broad peak in the range from 3000 to 3750 cm^{-1} was attributed to the presence of a hydroxyl group (-OH) and surface-adsorbed water. Figure 1(b) illustrates the FTIR bands observed at 1740, 1215, 1315, and 1500 cm^{-1} for the 35%NrGO and 45%NrGO samples as well as for 25%NrGO sample (except the bands at 1215 and 1315 cm^{-1}). The observed bands correspond to the residual C=O carbonyl groups, C=N stretching vibrations associated with pyridinic nitrogen, C-N stretching vibrations related to pyrrolic nitrogen, and the stretching vibration of C=C. However, the levels of pyridinic nitrogen and pyrrolic nitrogen in 25%NrGO are significantly lower compared to the other two materials. Following the introduction of nitrogen into the GO sheet, there was a notable decrease in the peak intensities associated with the oxygen-related groups, and the broad spectrum in the range of 3000 to 3750 cm^{-1} (-OH) was significantly diminished. The FTIR spectra indicate the concurrent reduction and nitrogen doping of 25%NrGO, 35%NrGO, and 45%NrGO.

Fig. 1(c) displays the Raman spectra of as-synthesized GO and NrGO with different nitrogen-doping amounts. The Raman spectrum of GO shows two major Raman peaks at 1351 cm^{-1} and 1600 cm^{-1}, which can be assigned to the D and G bands, respectively. The intensity of the D band is higher than that of the G band in GO, revealing the presence of many defects and oxygen functional groups in the as-synthesized GO. The intensity peak ratio (I_D/I_G) describes the nanomaterial quality and the corresponding concentration of sp^3 defects in the sp^2 hybridized graphene layer. Table I illustrates all NrGOs have a lower D to G ratio compared to GO, suggesting an increase in the size of C sp^2 atom clusters as a result of the simultaneous reduction of GO. Furthermore, an increment in the (I_D/I_G) ratio indicates the reduction of GO and the existence of nitrogen content owing to the extra scattering effect induced by electron doping. Also, it is noteworthy that the G band shifts with nitrogen doping.

Fig.2 presents scanning electron microscopic (SEM) images of GO and NrGO. Several wrinkles and corrugations are visible likely attributed to oxygen-related functional groups and nitrogen dopant elements. Fig. 2(b) illustrates that the wrinkles were more prominent in NrGO, indicating the influence of nitrogen doping on its

morphology. Fig. 3 illustrates the WS_2-35%NrGO nanocomposite, providing evidence for the growth of WS_2 on NrGO sheets.

Table I. Intensity of D and G bands, (I_D/I_G) ratio of NrGO samples

Material	Intensity of D band and G band, and (I_D/I_G) ratio		
	D band	*G band*	*(I_D/I_G) ratio*
WS_2-25% NrGO	368.49	373.16	0.986
WS_2-35% NrGO	811.89	805.67	1.007
WS_2-45% NrGO	364.35	373.16	0.976
GO	821.58	806.92	1.018

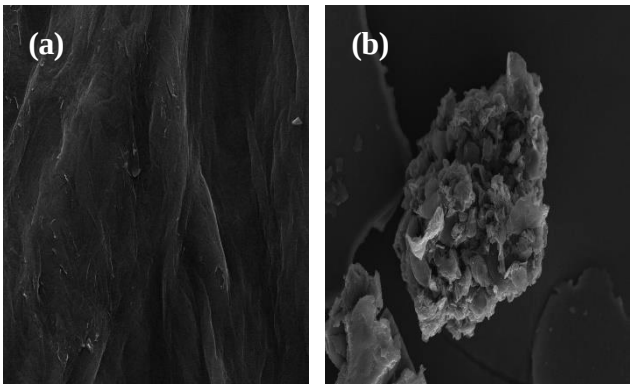

Fig. 2. SEM images of (a) GO and (b) 35%NrGO

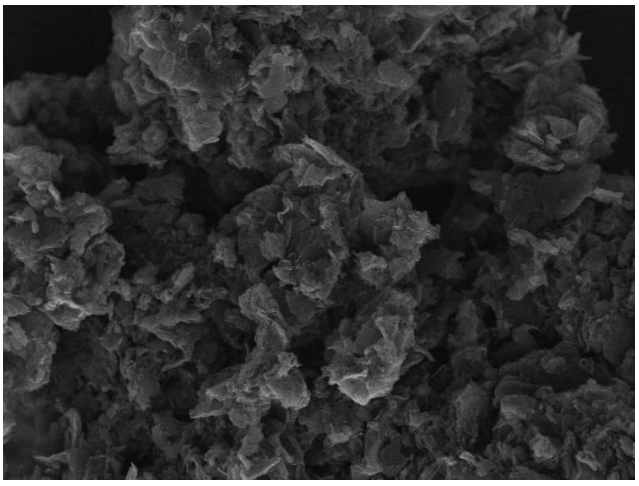

Fig. 3. (a) SEM images of WS_2-35%NrGO

The electrocatalytic HER performance of WS_2-25%NrGO, WS_2-35%NrGO, and WS_2-45%NrGO catalysts for comparison is illustrated in Fig. 3(a) – (c) and detailed in Table II. Initially, LSV measurements were performed in a 0.5 M H_2SO_4 solution at a scan rate of 5 mV s^{-1} under ambient temperature conditions. Figure 3(a) and Table II illustrate the enhanced catalytic performance of WS_2-35%NrGO, exhibiting an overpotential of -382.65 mV at a current density of -10 mA cm^{-2}, which is lower than that of WS_2-25%NrGO (-468.10 mV) and WS_2-45%NrGO (-394.86 mV).

In order to conduct a more comprehensive investigation of the HER activity, we fitted the linear portions of the Tafel plots to the Tafel equation expressed as follow (1).

$$\eta = a + b\log j \quad (1)$$

where j is the current density and b is the Tafel slope.
The Tafel slopes derived from the data in Figure 4(a) are displayed in Figure 4(b), and Table I indicates that the WS_2-35%NrGO material exhibits a lower Tafel slope in comparison to the other nitrogen-doped WS_2 materials. The Tafel slope of WS_2-35%NrGO was determined to be 105.01 mV dec^{-1} , suggesting a high level of hydrogen evolution reaction (HER) activity. The excessive presence of nitrogen dopants causes a decrease in conductivity, leading to a somewhat elevated Tafel slope (137.51 mV dec^{-1}) in WS_2-45%NrGO.

The HER mechanism in an acidic medium can be expressed by following steps (2) – (4).

$H_3O^+ + e^- \rightarrow H_{ads} + H_2O$ (2) ; Volmer reaction
$H_{ads} + H_3O^+ + e^- \rightarrow H_2 + H_2O$ (3) ; Heyrovsky reaction
$H_{ads} + H_{ads} \rightarrow H_2O$ (4) ; Tafel reaction

For the Volmer, Heyrovsky, or Tafel step to be the rate-determining step, the Tafel slope is anticipated to be 120, 40, or 30 mV dec^{-1} , respectively. A clear correlation exists between the Tafel slope and the step that most significantly limits the rate of the HER reaction. The slope of WS_2-35%NrGO gets closer to 120 mV dec^{-1}, indicating that the Volmer step plays a more significant role in the rate-limiting process, suggesting that this nanocomposite operates under a Volmer-Heyrovsky mechanism.

The electrochemical double-layer capacitance (C_{dl}), anticipated to be linearly proportional to the active surface area, was assessed to evaluate the effective electrochemical surfaces of the catalysts using cyclic voltammetric method. Fig. 4(c) and Table II illustrate that the C_{dl} values for WS_2-25%NrGO, WS_2-35%NrGO, and WS_2-45%NrGO are 0.976 mF cm^{-2}, 1.27 mF cm^{-2}, and 0.563 mF cm^{-2}, respectively. The resulting electrochemical active surface areas (ECSAs) are 48.79 cm^2, 63.50 cm^2, and 28.15 cm^2, respectively.

Table II. Electrochemical parameters of as-prepared WS2-NrGO

Material	Electrochemical parameters			
	Overpotential at -10 mA/cm^2 (mV)	*Tafel slopes (mV dec^{-1})*	*C_{dl} values (mF cm^{-2})*	*ECSA (cm^2)*
WS_2-25% NrGO	-468.10	122.02	0.976	48.79
WS_2-35% NrGO	-382.65	105.01	1.27	63.50
WS_2-45% NrGO	-394.86	137.51	0.563	28.15

The ECSA values were derived by the following formula (5).

$$ECSA = C_{dl}/C_s \quad (5)$$

where C_s is the specific capacitance (usually 20 μF cm^{-2})

This suggests that the electrochemical surface area of the electrocatalyst may decrease when the nitrogen doping level in graphene oxide is either too high or too low. This occurs because excessive nitrogen doping can lead to an excessive number of defects in the structure of GO. The presence of these defects interferes with the conjugated π electron system, which is crucial for optimal conductivity. Additionally, excessive nitrogen doping may lead to the aggregation or stacking of WS_2 nanoparticles on the GO support, thereby diminishing the available surface area for the HER reaction. Small amounts of nitrogen doping may not generate enough nitrogen functional groups to improve the electronic properties of GO. Generally, nitrogen doping improves the availability of active sites for hydrogen evolution reactions, but inadequate doping can lead to reduced activation of the WS_2 surface. Consequently, the findings suggest that a nitrogen doping level of 35% in GO represents the ideal amount for improving electrocatalytic activity in relation to HER. The ECSA values indicate that the WS_2-35%NrGO material has a greater number of effective active sites.

IV. CONCLUSION

By adjusting the nitrogen doping amount, we successfully synthesized nitrogen-doped reduced graphene oxide, which we then used as the growth substrate for WS_2 to boost its conductivity and electrochemical performance. Electrochemical measurements indicate that inadequate nitrogen doping can result in reduced activation of the WS_2 surface, and a nitrogen doping level of 35% in GO would be the optimal amount to enhance the electrocatalytic activity of WS_2 towards HER.

V. REFERENCES

[1] F. Liu, C. Shi, X. Guo, Z. He, L. Pan, . Z.-F. Huang, X. Zhang and J.-J. Zou, "Rational Design of Better Hydrogen Evolution Electrocatalysts for Water Splitting: A Review," *Advanced Science*, 2022.

[2] J. Wang, F. Xu, H. Jin, Y. Chen and Y. Wang, "Non-Noble Metal-based Carbon Composites in Hydrogen Evolution Reaction: Fundamentals to Applications," *Advanced Materials*, 2017.

[3] M. A. R. Anjum, H. Y. Jeong, M. H. Lee, H. S. Shin and J. S. Lee, "Efficient Hydrogen Evolution Reaction Catalysis in Alkaline Media by All-in-One MoS2 with Multifunctional Active Sites," *Advanced Materials*, 2018.

[4] D. (. Xia, F. Gong, X. Pei, W. Wang, H. Lia, W. Zeng, M. Wu and D. V. Papavassiliou, "Molybdenum and tungsten disulfides-based nanocomposite films for energy storage and conversion: A review," *Chemical Engineering Journal*, 2018.

[5] Y. Xu, R. Wang, J. Wang, J. Li, T. Jiao and Z. Liu, "Facile fabrication of molybdenum compounds (Mo2C, MoP and MoS2) nanoclusters supported on N-doped reduced graphene oxide for highly efficient hydrogen evolution reaction over broad pH range," *Chemical Engineering Journal*, 2021.

[6] X. Pu, J. Qian, J. Li, D. Gao and R. Zhang, "Adjusting the electronic structure of WS2 nanosheets by iron doping to promote hydrogen evolution reaction," *FlatChem*, 2021.

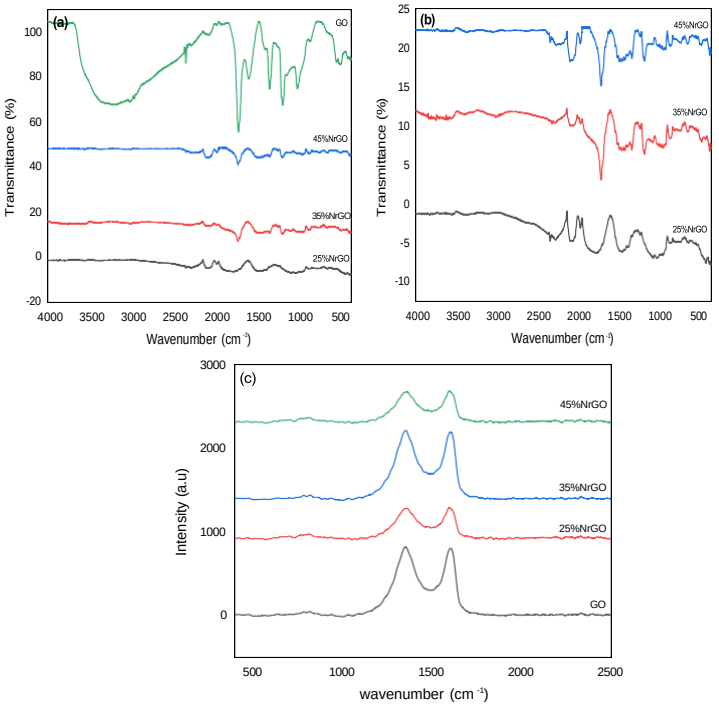

Fig. 1. (a) FTIR spectrum of 25%NrGO, 35%NrGO, 45%NrGO and GO; (b) FTIR spectrum of 25%NrGO, 35%NrGO and 45%NrGO; (c) Raman spectrum of 25%NrGO, 35%NrGO, 45%N-rGO and GO

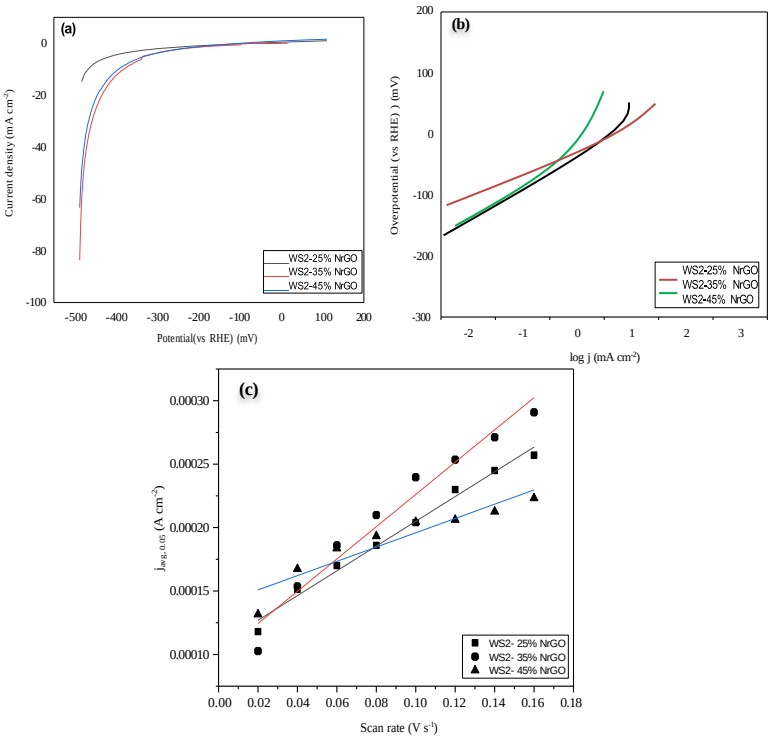

Fig. 4. (a) HER polarization curves and (b) corresponding Tafel plots for WS_2-25%N-rGO, WS_2-35%N-rGO, WS_2-45%N-rGO with a scan rate of 5 mV s^{-1} (c) Cdl estimation for assessment of electrochemical active surface areas of WS_2-25%N-rGO, WS2-35%N-rGO, WS_2-45%N-rGO

Electrical, Electronic, Mechanical and Systems Engineering

Incorporating the Signal Processing Elements in the Development of an Automatic Tire Inflation System

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***Abstract*— Tires are a critical component of any vehicle, providing essential properties such as traction, stability, and control while facilitating the connection between the vehicle and the road. Improperly inflated tires, under-inflated or over-inflated, are a common problem, leading to uneven wear, rough ride, reduced handling, increased rolling resistance, and reduced traction. The outcome of the research will be developing a tire pressure monitoring and refilling system with a monitoring panel for light vehicles by utilizing signal processing elements. An electrical circuit has been developed along with an algorithm. The code controlled the system, including measuring tire pressure when starting the vehicle, refilling low-pressure tires, releasing excess pressure, and detecting tire pressure errors. The system includes a display panel with LED indicators to show the tire pressure status. Safety features were added to the system, automatically cutting off the refill mechanism when the tire pressure reached the recommended level. The results were analyzed under the conditions namely, low- and high-pressure situations along with the air-filling and air-releasing situations. The system was validated with the indication of the LED luminosity. It can be summarized that the system is applicable for a light vehicle while reducing the cost, time, and tire wear with the ensured safety and stability. Further improvements were identified and suggested.**

Keywords*— Signal Processing, Tyre Inflation, Pressure, Display Panel

I. INTRODUCTION

Tires are a critical component of any vehicle, providing essential properties such as traction, stability, and control while facilitating the connection between the vehicle and the road. Recent advances in materials and design have improved tire performance, and the composition has incorporated natural and synthetic rubber with various additives and reinforcements, depending on the intended purpose. The main parts of a tire that collectively affect its performance include the tread, sidewall, bead, and inner liner.

Maintaining proper tire pressure is very important. Improperly inflated tires, under-inflated or over-inflated, are a common problem, leading to uneven wear, rough ride, reduced handling, increased rolling resistance, and reduced traction[1], [2]. Adhering to the recommended tire pressure range specified by the vehicle manufacturer is essential to avoid these problems and ensure safe, efficient, and comfortable driving. Tire pressure plays a dynamic role in fuel economy, vehicle performance, and safety. Properly inflated tires improve fuel efficiency, extend tire life, provide a smooth ride, and reduce the risk of accidents[3]. This has led to an increased focus on light vehicle tire inflation systems designed to monitor and maintain optimal tire pressure.

These systems use sensors and automated processes to continuously monitor tire pressure, providing real-time feedback to the driver and adding air when necessary to maintain the recommended pressure level. This not only improves safety, but also reduces the risk of accidents due to improper tire inflation, reduces fuel costs through improved efficiency, extends tire life by reducing uneven wear, and saves time by eliminating the need for frequent manual adjustments[4], [5].

The aim of this project is to develop a tire pressure monitoring and refilling system with a monitoring panel for light vehicles by utilizing signal processing elements. The objectives include Modifying the functional properties of the components of a wheel tire, Reducing time and cost for tire pressure while increasing vehicle safety and performance, finding an approach to reduce tire wear, and utilizing the in-built operational behavior of signal processing elements.

Inflation problems with tires are a common inconvenience for car owners, and it leads to faster and unnecessary payments. Various factors, including road conditions, heat, and weather, contribute to tire pressure fluctuations that are often invisible at first glance, and as a result, drivers don't realize their tires are under-inflated until problems arise, wasting both time and money[6]. The root cause of tire pressure problems seems to be a lack of knowledge about the appropriate pressure for the conditions. Neglecting tire care as well as driving on under-inflated tires will increase fuel consumption. Manual refilling is a time-consuming process. When traveling in remote or forested areas, finding a gas station can be difficult and maintenance can be problematic[7]. Installing an automatic tire inflation system in vehicles provides a practical solution. This system minimizes driver discomfort. Solves tire pressure problems and offers many advantages. However, it introduces certain challenges, including potential effects on

vehicle balance, increased power consumption, signal losses, and expensive components.

To overcome these challenges, the system must incorporate lightweight components, efficient sensors, compact, low-power modules, and high-quality, cost-effective elements. In essence, an automatic tire inflation system acts as a mechanism to reduce over-inflated tires and under-inflate them, ensuring that tires maintain the perfect pressure level under various conditions, thereby improving safety, fuel efficiency, and overall driving comfort.

II. METHODOLOGY

This project is to develop an automatic tire inflation system. The research began with a review of numerous articles to identify a research gap and gather information related to maintaining correct tire pressure and fault detection. Information on the advantages, disadvantages, and problems related to the tire system of selected light vehicles commonly used in Sri Lanka was collected from websites, magazines, and YouTube. The designed system included pressure sensors, a monitoring panel, a control unit, an air compressor, electromagnetic valves, hoses, wires, tires, and many other elements. Solid Edge software was used to create the system design. Simulation work and physical system development were then carried out.

Data were collected to understand tire pressure reduction methods, pressure monitoring, and refilling methods. Creates an electrical circuit to control air inflation. Then an algorithm was created. The code controlled the system, including measuring tire pressure when starting the vehicle, refilling low-pressure tires, releasing excess pressure, and detecting tire pressure errors. The system includes a display panel with LED indicators to show the tire pressure status. Based on the design, lathe work was done and the wheel hub was repaired to allow the passage of compressed air. A pressure detection sensor unit was developed using components such as a Bourdon tube pressure gauge, node MCU board, LDR sensor, and flashlight. The sensor unit worked by sending signals to the ECU when the shadow from the pressure gauge changed. The inflation mechanism included a compressor, rubber hoses, and a valve to refill the tires as needed. A user-friendly monitoring panel is designed to display real-time data and alert the driver when a tire's pressure is low. Extensive testing was conducted under various conditions to ensure system performance and durability.

Safety features were added to the system, automatically cutting off the refill mechanism when the tire pressure reached the recommended level. A working prototype of the system was developed for testing and evaluation, with plans for further improvements based on prototype data.

II.I. Signal Processing Flow Diagram

Figure 01 below shows how to control signals. First, the tire pressure is measured by the sensor unit. It shows if the tire pressure is at the right level. If the pressure is low, it will be indicated by a symbol and the compressor will be turned on. It is indicated by another disease until it reaches the right level. After reaching the correct pressure, the timer checks if there is any further pressure variation, otherwise the compressor is turned off. If there is a warning, the compressor maintains the pressure. If the pressure is high, the pressure release valve reduces the pressure until it reaches the right level.

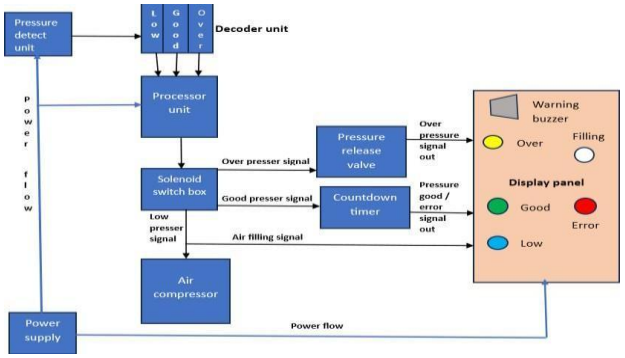

Fig. 1. Signal Flow Diagram

II.II. Component Selection

The component selection comprises two stages namely, mechanical and electrical. The tables shown below summarize the components along with their features.

TABLE 01: Selection of Mechanical Components

Component	Description
Wheel Hub	A wheel hub is an essential part of the unit, and its main job is to ensure a safe and smooth connection between the wheel and the axle. The air-flowing grooves are cut in it.
Iron rod	An iron rod was taken to make the bush. Iron was chosen because of its strength.

TABLE 02: Selection of Electrical Components

Component	Description
Pressure Gauge	The Pressure gauge is used to make the sensor unit by using its basic applications, measuring and indicating the air pressure in a system.
LDR (Light Dependent Resistor)	After reaching each pressure level according to the movements of the air pressure gauge indicator, the pressure level data is captured according to the LED signals related to those pressure levels.
LED (Light Emitting Diode)	For Light – indicating purposes

TABLE 03: Components of the Control Units

Components	Description
Solenoid Valve	An Electromechanical device that helps to control the refiling and overloading release of the air. It only opens to one side so it acts as a one-way door. It simply on/off of air flow frequently.
Relay switch	This turns ON and OFF the electrical parts of the circuit by the given switching signals for each condition.

TABLE 04: Components of the Panelboard

Components	Description
Enclosure Box	The Circuit must be put inside this box. The dimensions of the fixed circuit were 110 × 110 mm. A 200×120×55mm box was selected.
I2c Module	This communicates each event as characters to be displayed on the LCD screen over two wires that include a face date line and a clock line.
LCD (Liquid Crystal Display)	By this, the state indicating characters given about each situation will be displayed on the LCD screen.
Node MCU Board	The ESP8200 Wi-Fi module is the foundation of the Node MCU board, a development platform. Prototyping thanks to its user-friendly development environment and support for several programming languages, including Arduino, this platform makes it simple to test out IoT concepts.

III. RESULTS AND DISCUSSION

The results of the experiment can be summarized as follows:

If the tire has low pressure, the sensor unit detects and sends the data to the processor unit. It sends signals to open the solenoid valve and turn on the compressor. Low-pressure detection will be indicated by LED. If there is too much pressure in the tire (this happens only after tire change or external maintenance), the sensor unit detects and sends the data to the processor unit. It sends signals to open the pressure release valve. High-pressure detection is indicated by LED. The timer will run twice. The first one is when the vehicle is started and the other is after the automatic refill. The timer will run for 5 minutes after activation. It automatically cuts off if there is no pressure drop. This will be indicated by an LED. Once the compressor is turned on, the compressor supplies air to the tire. In this case, the fill LED will show until the sensor unit detects that the tire is filled to the correct pressure, the compressor will cut off and the LED will turn off.

When the pressure release valve opens, the pressure will slowly release until the pressure reaches the correct level. This total time will be indicated by LED. After activating the timer, it will work for 5 minutes to detect any fault. If the sensor unit detects a sudden drop in pressure, it will be a fault (tire punch). This is indicated by an LED and a warning buzzer. It should be noted that there are separate LEDs for all these situations.

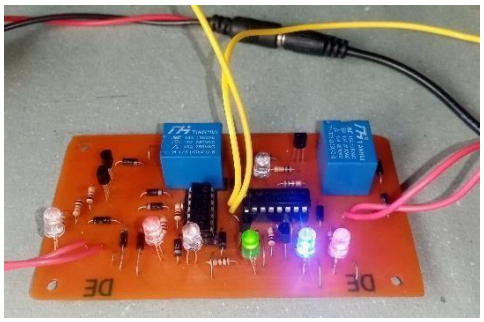

Fig. 2. High Pressure Detecting time

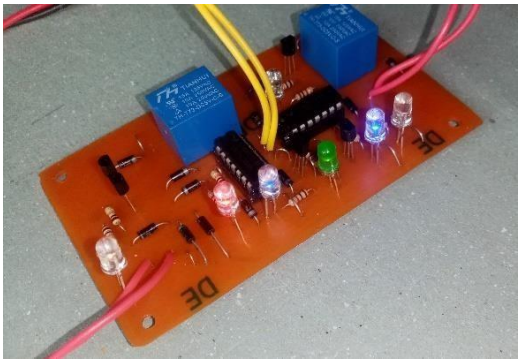

Fig. 3. High Pressure Releasing time

Figures 2 and 3 state two different conditions of the experimentation. They describe the detection time and the release time respectively.

There are a few recommendations that can be made based on the systematic implementation of the signal-processing elements. Firstly, the development of a system to automatically vary tire pressure according to road conditions. By keeping proper pressure on the tires according to the condition of the road, the safety of people and reducing the wear of the tires can be achieved. GPS technology and both ultrasonic and image detection technology can be used for this. Since a NODE MCU board is used, the nature of the road can be identified by GPS by providing a WIFI connection. Instantly reducing the pressure will disturb the system, so knowing in advance and gradually reducing or increasing it will ensure the safety and stability of the system and the vehicle. The combination of ultrasonic and image detection technologies adjusts the system based on temporary obstacles in the road. After collecting the appropriate tire pressure data for each road, it can be installed in the microcontroller and the operation of the system can be handled accordingly.

Secondly, an Improved system for tire pressure variation according to the vehicle speed and weight distribution. A sensor that detects weight is attached to the suspension

system, then takes the weight and detects the speed from the wheel speed sensor. By taking the signals from both sensor types, change the tire pressure automatically by matching those two. However, for this, data must be taken and mapped beforehand. This is useful for traction control and safety.

The research identifies some flaws in the finding. The optimized results was not able to produced to refilling system as it has to be further analyzed and modified. Thus, the findings can be applied for the comparative study on the application of similar system in the tyre inflation.

IV. CONCLUSION

The automatic tire inflation system is a real-world problem solver for light vehicles. It will help to reduce cost, time, and tire wear while ensuring safety and stability. By using the electronic control panel, controlling the system is efficient and effective. Developing a tire pressure monitoring and refilling system with a monitoring board for light vehicles using signal processing elements and the objectives of improving vehicle performance, improving tire pressure efficiency, improving safety and performance, and reducing costs was successfully achieved by doing this research.

REFERENCES

[1] A. Bade, V. S. Akhade, M. Dangwal, S. Hatkadke, and Prof. S. Patil, "Online Tyre Inflation System," 2017. [Online]. Available: https://api.semanticscholar.org/CorpusID:212520081

[2] M. J. Rajkumar,"AUTOMATIC TYRE INFLATIONSYSTEM,"2017.[Online].Available:https://api.semanticscholar.org/CorpusID:212489224

[3] M. Reiter and J. Wagner, "Automated Automotive Tire Inflation System – Effect of Tire Pressure on Vehicle Handling," IFAC Proceedings Volumes, vol. 43, no. 7, pp. 638–643, 2010, doi: https://doi.org/10.3182/20100712-3- DE-2013.00013.

[4] J. Vishweshver. and S. Haider, "Auto Tyre Pressure Inflation System,"2020.[Online].Available:https://api.semanticscholar.org/CorpusID:222260638

[5] S. Adakmol, T. G. Shende, D. Poriya, and S. Fotedar, "Central Tyre Air Inflation System," International Journal for Scientific Research and Development, vol. 4, pp. 1426–1429, 2016,[Online].Available: https://api.semanticscholar.org/CorpusID:159260978

[6] T. R. Pletts, "A LITERATURE OVERVIEW OF CENTRAL TYREINFLATIONSYSTEMS,2006.[Online].Available:https://api.semanticscholar.org/CorpusID:11032213

[7] T. Mushiri, A. Muzhanje, and C. Mbohwa, "Design of an automatic tire pressure inflation system for small vehicles,"2016[Online].Available:https://api.semanticscholar.org/CorpusID:116350755

Sustainable Agriculture, Environment (Agriculture)

Utilizing Hypocotyl Color as a Phenotypic Marker for Enhancing Disease Resistance and Fruit Quality in *Solanum lycopersicum* F3 Generation: A Pedigree Selection Study Focused on *Phytophthora infestans* and *Alternaria solani*.

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***Abstract*- Tomato is one of the most important crops in agriculture; hence, optimization of its breeding program for the development of better cultivars and improved disease resistance is a key target. The present study tries to facilitate the selection of elite varieties from the large breeding program by easily identifiable phenotypic markers like hypocotyl color, associated with the disease-resistant trait. The present work implements the use of phenotypic markers for disease resistance and improvement of fruit quality in *Solanum lycopersicum* F3 generation pedigree selection. A hybrid of the BAX247 variety of tomatoes derived from PGRC in Sri Lanka was intercrossed to derive the progeny possessing the RR gene allele linked to the dominant R gene responsible for providing resistance against *Phytophthora infestans* and *Alternaria solani*. In other words, it means that the major role of a resistance gene is to recognize a pathogen and subsequently trigger plant defenses. All 26 breeding lines were phenotype evaluated at RARDC Bandarawela, and a strong association of purple hypocotyls with the RR allele was observed, verified by Chi-square analysis. The purple and green hypocotyl traits were proved to be a reliable marker for selecting disease resistance. These findings emphasize that hypocotyl color can be used as an efficient phenotypic marker in breeding programs, which is essential for further advances in tomato production through the development of cultivars with increased resistance and superior agronomic traits. Improved breeding techniques via such markers can meet important challenges in tomato cultivation and thus increase yield stability and quality.**

Keywords - Tomato breeding, phenotypic markers, disease resistance, Hypocotyl color, RR gene allele, pedigree selection, *Solanum lycopersicum*, anthocyanin, BAX247, R gene.

I. INTRODUCTION

The plants must be disease-free to maintain the health, productivity, and economic viability of the produce. Diseases caused by ***Phytophthora infestans*** and ***Alternaria solani*** can seriously reduce tomato yield, quality, and market value, resulting in substantial losses among growers [1]. Growing resistant tomato varieties minimizes these risks, reduces the use of chemical applications, and strengthens the general resistance of the crops [2]. This not only contributes to higher and more consistent yields but also supports sustainable agriculture practices. Sustainable tomato production emphasizes reduced adverse environmental impacts of farming operations, reduced dependence on chemical inputs, and better soil health [4]. The disease-resistant cultivars stand crucially in this paradigm by reducing disease incidence, thus minimizing the cost due to frequent pesticide applications, resulting in environmental stewardship and economic sustainability in tomato farming [5].

A. Challenges and Significance of Disease Resistance in Hybrid Tomato Cultivation: Managing Late and Early Blight in Uva, Sri Lanka

This is in contrast to tomato production, like in the Uva region of the land in Sri Lanka, which is challenged by hybrids and disease management. Hybrids are usually bred to combine positive characteristics like increased yield and improved fruit quality. The growing of hybrids further complicates disease management since they introduce genetic variation, and this may likely be responsible for an unpredictable response and a loss of resistance with time [6]. This is trended by the nature of diseases that have prevalence: late blight (***Phytophthora infestans***) and early blight (***Alternaria solani***) cause a major threat to tomato farming in Uva.

It is fast spreading and causes severe foliar and fruit damage, especially when caused by ***Phytophthora infestans***. Blight is most severe in moist, cooler conditions typical of Uva and is always coupled with high crop losses, constituting quite a serious challenge for farmers in several respects [7]. Early blight, caused by ***Alternaria solani***, is highly responsible for premature leaf drop and reduced fruit quality, adding up more expenses for the grower [8].

Better management of these blights lies in developing disease-resistant varieties. This makes disease resistance one of the few effective ways that can lower the incidence and prevalence of late and early blight, hence an available practical solution that can help to mitigate the challenges

from these diseases. Such varieties will increase resilience in crops and reduce dependency on chemical control, which is demanding on the environment and not helpful for the economic sustainability of the farmer [9]. With the incorporation of resistance genes in the tomato varieties, breeders can enhance sustainable defense through these spreading diseases and ultimately reduce the effect of these blights on tomato production in Uva, Sri Lanka.

B. Importance of Screening Tomato Accessions for Disease Resistance and the Implementation of Pedigree Selection and Mendelian Inheritance

Tomato accessions need to be tested because the resistant cultivars of diseases like late blight caused by ***Phytophthora infestans*** and early blight caused by ***Alternaria solani*** need to be identified and developed. This process helps in selecting varieties with inherent resistance, ensuring improved yield and quality [1] ; [7]. Pedigree selection allows breeders to trace and enhance desirable traits across generations, building a strong genetic base for disease resistance [12]. Understanding Mendelian inheritance principles further supports effective breeding by predicting trait inheritance patterns, and facilitating the development of robust, disease-resistant tomato varieties.

C. RR Gene Inheritance Pattern

The inheritance pattern of the RR gene, conferring resistance to diseases like late blight caused by ***Phytophthora infestans*** and early blight caused by ***Alternaria solani***, complies with Mendel's law on:

The general understanding is that RR is a dominant gene characterized by providing disease resistance. Two alleles have been found: the dominant R allele conferring resistance and the recessive r allele conferring no resistance [10].

- Parental Generation (P): By crossing two homozygous resistant plants (RR), all the offspring in the F1 generation inherit one R allele from each parent, hence the result is F1 uniformly heterozygous (Rr) and resistant plants
- F1 Generation: The F1 generation expresses the resistant phenotype because of the dominance of the R allele. Heterozygous (Rr) plants still express resistance due to the masking of the effect of the r allele by the dominant R allele.
- F2 Generation: Upon intercrossing F1 plants, F2 generation reveals the Mendelian ratio of 3:1 of resistant to susceptible plants. The genotype ratio is :
    - RR (homozygous dominant): Resistant
    - Rr Heterozygous dominant: Resistant
    - rr (homozygous recessive): Susceptible
- The phenotypic ratio for the expected result is 3 resistant plants (RR or Rr) to 1 susceptible plant (rr) [12].
- Implication for Breeding: With this pattern of inheritance, breeders can forecast and select disease-resistant plants with confidence to develop varieties whose traits would be assuredly expressed in successive generations [1].

The RR gene provides disease resistance against late blight (***Phytophthora infestans***) and early blight (***Alternaria solani***), among others, in a pattern of Mendelian inheritance that can be tracked with phenotypic markers with high efficiency, such as hypocotyl color [10]. In tomato plants, the purple-colored hypocotyls resulting from increased anthocyanin accumulation are highly correlated with disease resistance [1]. By incorporating these phenotypic markers, it will be easy for breeders to identify and select those plants possessing the RR gene. This would alleviate the complication of their work in breeding, ensuring that every new generation expresses uniform resistance to diseases; hence, the resistant plants can be reliably reproduced from seeds. This method reduces farmer dependency on hybrids for that certain crop [12]; [9].

MATERIALS AND METHODS

A. Plant Material and Study Location

The research was conducted at the Regional Agricultural Research and Development Center (RARDC) in Bandarawela, Sri Lanka, using the BAX247 tomato variety, a hybrid provided by the Plant Genetic Resources Centre (PGRC) in Sri Lanka. This study focused on the F3 generation derived from intercrossing BAX247 hybrids, with a total of 720 plants considered as individual treatments. The F3 generation exhibited a complex genetic structure with three types of gene alleles RR, Rr, and rr following Mendelian inheritance patterns.

B. Experimental Design

The experiment was conducted using a randomized complete block design (RCBD) to account for environmental variability and ensure robust data analysis. A total of 720 tomato plants, representing the F3 generation derived from BAX247 hybrid intercrosses, were treated as individual treatments. These plants were distributed across 26 breeding lines, each line varying in the number of plants it contained and randomly selected 26 individual progenies were by visual observations of key fruit quality parameter holders were evaluated for the fruit quality. The primary objective was to identify and evaluate the association between phenotypic markers, such as hypocotyl color, and disease resistance traits governed by the RR gene.

C. Field Layout and Planting

The experimental field was divided into blocks, each containing an equal number of plants from every breeding line to minimize the effects of environmental gradients across the field. The field was prepared with rows spaced 80 cm apart and individual plants spaced 40 cm apart within each row. This spacing was chosen to ensure optimal plant growth minimize competition for resources and ease the observation process.

D. Fertilization and Soil Preparation

Soil fertility and nutrient management were well taken care of to ensure the best plant growth and expression of relevant phenotypic characters. Well-composted poultry manure at 10 tons per hectare was applied to the soil two weeks before

transplanting. This organic amendment represented the main source of nitrogen, phosphorus, and potassium, but also other micronutrients necessary for good plant nutrition.
In addition to the organic amendment, a balanced chemical fertilizer with an N: P: K ratio of 3:2:2 was applied at the rate of 300 kg per hectare three days before transplanting. This kind of fertilizer formulation was selected based on the response to the results from the soil test aimed at correcting nutrient deficiencies with an immediate boost of nutrients to newly transplanted plants. Fertilizers were applied by broadcasting, and then a slight incorporation into the topsoil was done in such a way that the nutrients were made more available to the roots.
Measurements of soil pH and texture and their monitoring and adjustment were affected by the placement of lime in acidic soils to increase soil pH to a target range of between 6.0 and 6.5 for the promotion of tomato growth. It also makes better soil aeration and water infiltration because deep tillage before planting was done to encourage better root penetration.
The whole fertilization and soil preparation method greatly made it easy and ensured a balanced nutrient supply to the tomato plants over the entire course of growth, which ultimately gave high growth and successful expression of disease resistance traits phenotypically marked.

E. Nursery Preparation and Hardening

Superior seed selection was made from the BAX247 tomato variety. Seeds were sown in nursery trays constructed in half-burned paddy husk and mixed with coir dust in a 1:1 proportion, kept in a well-drained growth medium having requirements of aeration, moisture retention, and nutrient availability appropriate for good seedling development.
Seeds were sown to a depth of about 1 cm since it would ensure uniform germination. The seedbeds were covered with a protection package to protect the young seedlings against harsh environmental conditions, such as direct sunlight, heavy rain, and even pests. Watering began with a fine mist for the seedbeds to get adequate moisture but not cause waterlogging or dislocating the tender seedlings.
The seedlings were checked regularly for sickness, and when one was indicated, it was removed to avoid infection throughout the nursery stage. The seedlings were also fertilized once a week with a dilute solution of a balanced liquid fertilizer in the ratio of N: P: K 1:1:1 to support healthy growth.

After 21 days of stay in the nursery, the seedlings were gradually hardened to acclimatize them before finally transplanting them into the field. Hardening was affected by gradually increasing exposure to outdoor conditions by reducing the cover throughout 7 to 10 days and allowing greater irradiation from the sun with the subsequent first increasing and then decreasing temperatures.
Hardening off: This was done by initially limiting watering during this phase to acclimatize seedlings to lower moisture conditions and, in the process, encourage good rooting. On the final day of hardening, a complete water break was imposed, with 24 hours of no water being applied before transplanting to acclimatize the seedlings to further toughen them and reduce transplant shock.

Transplantation of the seedlings was carried out the following day during the early hours of daylight, which minimized the hardening-off intervals and gave them the maximum chances of establishment in the field. This systematic hardening ensured that the seedlings were well acclimatized to open field conditions and, therefore, better survival with vigorous early growth.

F. Monitoring and Data Collection

Systematic monitoring and data collection were part of the study to allow for detailed and correct information on the growth, phenotypic traits, and disease resistance of the 720 tomato plants. The monitoring was thorough and consistent, ensuring the reliability and reproducibility of the data.

During the growing season, plants were closely and routinely observed to score different sets of growth parameters, which included parameters of plant height, leaf number, and general vigor, from two weeks after transplanting to the maturity of the fruit at biweekly intervals. Any physiological stress like wilting, chlorosis, or abnormal growth patterns is noted as soon as it makes an appearance and is immediately treated appropriately with cultural practices or treatments.
The major phenotypic trait of interest is hypocotyl color, which was measured at the seedling stage and again during early vegetative growth. Hypocotyl color can be green or purple. Purple hypocotyls have higher anthocyanin content and may be resistant to some diseases. Other recorded traits included the shape of leaves and fruit characters, recorded during the adult plant stage.

Selections were screened systematically for resistance to ***Phytophthora infestans*** (late blight) and ***Alternaria solani*** (early blight). For each of the two diseases disease assessments were initiated as soon as symptoms were noticed and subsequently weekly. Disease severity was recorded on a 1-5 grade with the scoring system recommended by Aktar et al. (2011), with 1 being highly susceptible and 5 being immune. Data regarding the severity of the disease were collected for each individual plant to support a detailed analysis of resistance levels across the population.

Figure1: Immune Progenies for Late Blight

Figure2: Susceptible Progeny for Late Blight

The quality in terms of the fruits was analyzed at the peak period of the harvest. Five fruits each were randomly picked

from each of the 26 selected plants; the pericarp thickness, pH value, Brix, mass, width, and length were measured. Measurement will be done using own standard laboratory techniques, putting emphasis on uniformity in the management and processing of the samples

All data were recorded in field notebooks and digital devices with maximum care to ensure no data were lost. Data entry was a daily activity with cross-checking whenever needed to ensure the accuracy of the data. Digital tools also supported data management and initial analysis; it was possible to monitor the trends and observe real-time tracking to spot any possible anomalies that were detected by following the dataset.

Results of Duncan's multiple range test revealed that Plant 9 (L120-16), which exhibited a green hypocotyl, consistently ranked in the top performance group (Group A) for several critical traits, specifically pericarp thickness (Y1), Brix value (Y4), fruit length (Y5), and fruit width (Y6), making it a superior candidate compared to other evaluated plants. Although it showed a slightly lower ranking in fruit weight (Y3), its overall dominance in Group A for the remaining attributes supports its selection as the best candidate for breeding.

Figure 3: Selected Fruits - Labeled

Figure 4: pH measuring

Statistical analyses were run upon the completion of data collection to test how the differences found among treatments might be significant. ANOVA was carried out with the view of establishing the differences in means of the different breeding lines based on the phenotypic traits, disease resistance ratings, and fruit quality attributes. In addition, by utilizing chi-square analysis, an analysis incorporating frequencies of hypocotyl colors in regarding presence/absence of the RR allele, it would add more information about the efficiency of hypocotyl color for phenotypically marking against disease resistance.

CONCLUSION

This research indicates the use of hypocotyl color as a phenotypic marker in a pedigree selection for disease-resistant and fruit-quality improvement in the F3 generation of ***Solanum lycopersicum***. However, the significant p-value of this association of hypocotyl color was not strong enough to be used singly as a predictor of the disease resistance trait. This provides a very useful avenue for further research. This genetic map of the linkage between loci for hypocotyl pigmentation and disease resistance gives the idea that complex interrelations between the traits with secondary metabolites, such as anthocyanin, may involve loci.

Table 1: P -Values and the Interpretations of Findings

Variable 1	Variable 2	Pearson Correlation Coefficient (r)	Significance (p-value)	Interpretation
Disease Severity (Phytophthora)	Hypocotyl Color	-0.160	< 0.001	Moderate negative correlation: As hypocotyl color changes from purple (1) to green (2), Phytophthora severity tends to decrease (significant).
Disease Severity (Alternaria)	Hypocotyl Color	0.319	< 0.001	Moderate positive correlation: Green hypocotyls (2) are associated with higher Alternaria severity (significant).
Disease Severity (Phytophthora)	Disease Severity (Alternaria)	-0.080	0.031	Weak negative correlation: Plants with more severe Phytophthora tend to have slightly less severe Alternaria infections (significant).

Such weak but highly significant correlation between green and purple hypocotyl and improved resistance underlines the need for the incorporation of multi-trait analysis into pedigree selection.

Further studies are required to investigate the hypocotyl color trait and its control shortly, including its genetic architecture and biochemical interaction, to fully exploit this trait as a definitive marker. This will enable more effective breeding with increased precision in the development of tomato cultivars showing enhanced superior disease resistance.

While these results provide the basic understanding of the concept of using hypocotyl color as a phenotypic marker, further research will be necessary for its validation and fine-tuning of the expression to be used with complete confidence in breeding programs focused on the selection of disease-resistant tomato varieties.

REFERENCES

[1] Jones, J. D. G., Vance, C. P., & Goff, S. A. (2014). ***Phytophthora infestans*** *and the quest for disease resistance*. Current Opinion in Plant Biology, 20, 18-24.

[2] Oda, M., Horiuchi, S., & Uchiyama, T. (2018). ***Alternaria solani*** *and its impact on tomato production*. Journal of Plant Pathology, 100(2), 203-210.

[3] Rosenzweig, C., Hillel, D., & Iglesias, A. (2020). *The role of disease-resistant varieties in sustainable agriculture*. Agricultural Systems, 182, 102823.

[4] Pretty, J., Toulmin, C., & Williams, S. (2018). *Sustainable intensification in agriculture*. Nature Sustainability, 1(8), 378-390.

[5] Khan, M. I. R., Shiroto, K., & Nishimura, S. (2021). *Environmental and economic benefits of disease-resistant tomato varieties*. Crop Protection, 147, 105713.

[6] Gonzalez, S., Mazzeo, M., & Vannini, A. (2016). *Challenges in hybrid tomato cultivation: The impact of genetic diversity on disease management*. Journal of Agricultural Science, 154(5), 927-939.

[7] Haverkort, A. J., Kessel, G. J. T., & Goud, J. (2016). Late blight in tomato: A review of factors influencing disease development and management. Plant Pathology, 65(1), 30-47.

[8] Fry, W. E., Goodwin, S. B., & Matuszak, J. (2015). *Early blight of tomato: Understanding the impact and control strategies*. Phytopathology, 105(7), 934-945.

[9] Haggag, W. M., Al-Msiedi, M. H., & Ahmed, M. A. (2020). Disease-resistant tomato varieties: Benefits and strategies for managing late and early blight. Crop Protection, 135, 104623.

[10] Bai, Y., & Lindhout, P. (2007). Domestication and Breeding of Tomatoes: What have we gained and what can we gain in the future?. Annals of Botany, 100(5), 1085-1094.

[11] Hartl, D. L., & Ruvolo, M. (2012). *Essential Genetics: A Genomics Perspective*. Pearson Education.

[12] Singh, R. K. (2015). *Plant Breeding: Principles and Methods*. Kalyani Publishers.

Effect of Potassium Levels on Yield and Biochemical Properties of Hydroponically Grown Lettuce Varieties

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Abstract*— Hydroponics is an innovative alternative to traditional soil-based agriculture which addresses challenges such as soil-borne diseases and shortage of fertile land due to urbanization. Potassium is a crucial nutrient for plants influencing various physiological processes. An optimum potassium level is crop specific and dependent on various environmental factors. This study was designed to investigate the impact of potassium on yield, morphological parameters, and nutritional composition of two lettuce (*Lactuca sativa*) varieties; Lollo Bionda and Red Oak grown in a Nutrient Film Technique. AiGrow™ nutrient solution was formulated with four different potassium concentrations as: 300 ppm, 350 ppm, 400 ppm, and 492 ppm (control). The plants grown under each potassium condition (n=8) were tested for morphological parameters and spectrophotometric assays were conducted to analyze total protein, carbohydrate, phenol, and flavonoid contents. Compared to the control group, 300ppm group displayed the highest leaf number (30.5) and leaf area (248.9 mm^2) in Red Oak. However, in Lollo Bionda the control group (492 ppm) displayed the highest leaf number (26.75), leaf area (149.49 mm^2) and fresh weight (97.74 g). For Lollo Bionda, 300 ppm concentration was ideal for the highest nutritional content and 350 ppm for Red Oak. However, there were no distinctive trends observed in the biochemical parameters with increasing Potassium concentrations. Based on these results, it can be suggested that the original potassium level of 492 ppm in AiGrow™ nutrition solution can be reduced further to obtain a higher and more nutritious lettuce yield. Further research under more optimized growth conditions is required to validate these findings.

Keywords—Hydroponics, Potassium Level, Lollo Bionda, Red Oak, Nutrient Film Technique (NFT)

I. Introduction

Soil-less agriculture involves growing plants in a nutrient-rich solution, with an inert medium such as coconut coir, rock wool or vermiculite, for mechanical support [1]. The principle is the direct up-take of nutrients, by the roots, from a nutrient solution designed specifically to each plant's requirement. The growing global demand for hydroponic agriculture, owes to its sustainability, less land requirement, water conservation and limited use of fertilizers [2]. This method allows precise control over factors including pH, temperature, light intensity, Electrical conductivity (EC), playing an important role in plant growth [3]. The NFT system contains channels, where plants are submerged in a nutrient solution, circulated by a pump.

Potassium (K) is a primary plant nutrient, impacting plant growth and yield. It plays a vital role in translocation, turgor pressure maintenance and disease resistance. As per existing studies, higher chlorophyll content, higher leaf number, and increased leaf area ratio are consistent, with increased levels of potassium in lettuce [4].

Lettuce (*Lactuca sativa*) is considered as a functional food, which is rich in vitamins (A, K and C), fiber and minerals. Moreover, it is low in calories, fat, and sodium [5]. The research is done on the two lettuce varieties Lollo Bionda (*Lactuca sativa* var. *crispa*) and Red Oak (*Lactuca sativa*). Easily achievable growth conditions (6-6.5 pH and 2-2.5 dSm^{-1} EC), short growth period and large global market were the reasons to select these two varieties for the present study.

The main aim of this study was to identify the ideal K level to obtain a lettuce harvest, which contains a shorter stem, higher leaf number and larger leaf area. Furthermore, the effect of varying K levels on the yield, nutritional composition, and bioactive compounds were also evaluated.

II. Materials And Methodology

This plants were grown in the greenhouse of AiGrow (Private) Limited located in Colombo 10, Sri Lanka.

A. Seed Germination

Lollo Bionda and Red Oak seeds (Rijk Zwaan) were placed in soaked 28mm soil pellets. From each variety, 32 seeds were used. The pellets were watered everyday with tap water for four weeks and kept in standard greenhouse conditions (Temperature: 60°C and Relative Humidity (RH): 60%).

B. Nutrient Solution Preparation

The AiGrow™ nutrient solution was formulated with four different K levels as, 300 ppm, 350 ppm, 400 ppm and 492 ppm. The original solution with 492 ppm was used as the control. The EC levels were maintained at 2.5 mS/cm and pH at 6.5, with the addition of base (KOH) or acid (H_3PO_4).

C. NFT System Set-up and Plant Growth

Four NFT channels were set up (one for each concentration) and each channel was directed to a 15L nutrient solution reservoir. The circulation of solutions to each channel was done using identically powered submersible pumps.

Four weeks after seed germination, the plants were transferred to the NFT system (eight sprouts from each variety into each concentration channel) as shown in Fig. 1. The leaf number, leaf area and plant height were measured weekly, until harvested after 5 weeks.

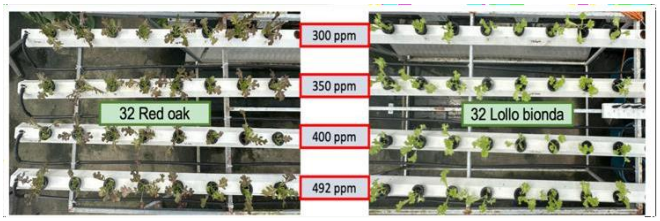

Fig. 1. NFT set up with two lettuce varieties in four concentration channels

D. Preparation of Aqueous Plant Extracts

Plants were harvested after 5 weeks of growth and the fresh weight was recorded. Then, the plants were shredded and were dried in a hot air oven at 40°C for 48 hours. Dried samples were ground mixed with water at a ratio of 1:20 and heated at 90°C, in hot air oven for 15 minutes. The cooled mixture was filtered to produce aqueous plant extracts, which was diluted at 1:10 ratio for further biochemical analyses.

E. Determination of Total Carbohydrate Content (TCC)

Phenol-sulfuric spectrophotometric assay was followed using 5% phenol and 96% sulfuric acid (Absorbances measured at 470 nm). TCC was determined in correspondence to a dextrose standard series (concentrations 50-250 µg/ml) [6].

F. Determination of Total Protein Content (TPrC)

Lowry assay was followed according to the method stated by Waterborg [7]. TPrC was determined by corresponding the absorbances measured at 660 nm, with a Bovine Serum Albumin (BSA) standard series (concentrations 200-1000 µg/ml).

G. Determination of Total Phenolic Content (TPC)

The Folin-Ciocalteu colorimetric method was followed to determine the TPC, using 10% Folin-Ciocalteu reagent and 7.5% Na_2CO_3 (Absorbances measured at 765 nm using UV-vis Spectrophotometer) [8]. The gallic acid standard series contained varying concentrations of 20-100 µg/ml.

H. Determination of Total Flavonoid Content (TFC)

Aluminium chloride spectrophotometric assay was followed according to Rao [9], with 10% $AlCl_3$ and 1M potassium acetate. Absorbances were measured at 415 nm and corresponded to a quercetin standard series (concentrations 20-100 µg/ml).

I. Statistical Analysis

All graphs were generated using Microsoft Office 365 Excel. The IBM SPSS Statistics Version:27.0.1.0 was used for statistical analysis with one-way ANOVA followed by LSD (Least Significant Difference) for multiple comparison analysis. A p value less than 0.05 was considered as statistically significant.

III. Results And Discussion

Fig. 2. represents the results of the average leaf number at week 5.

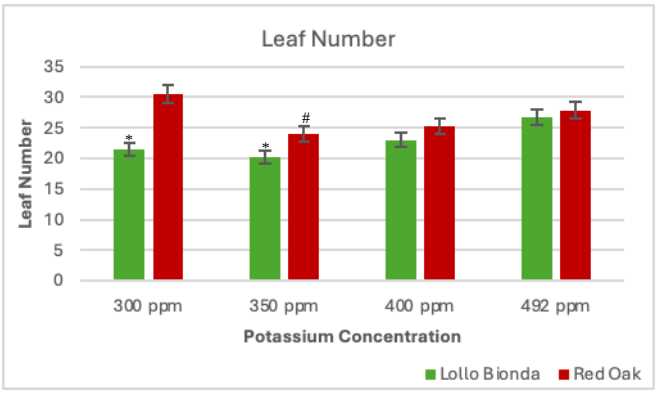

Fig. 2. Average leaf number of Lollo Bionda and Red Oak under each K condition. All values are expressed as the mean ± S.E. Statistical analysis was conducted by one-way ANOVA followed by LSD for multiple comparison analysis. * represents p<0.05 compared to Lollo Bionda 492 ppm control group and # represents p<0.05 compared to Red Oak 492 ppm control group.

Fig. 3. shows the results of the average leaf area at week 5.

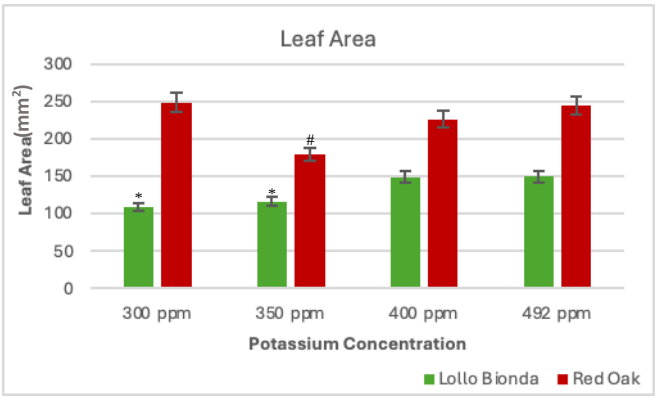

Fig. 3. Average leaf area of Lollo Bionda and Red Oak under each K condition. All values are expressed as the mean ± S.E. Statistical analysis was conducted by one-way ANOVA followed by LSD for multiple comparison analysis. * represents p<0.05 compared to Lollo Bionda 492 ppm control group and # represents p<0.05 compared to Red Oak 492 ppm control group.

Fig. 4. shows results of the average plant height (week 5).

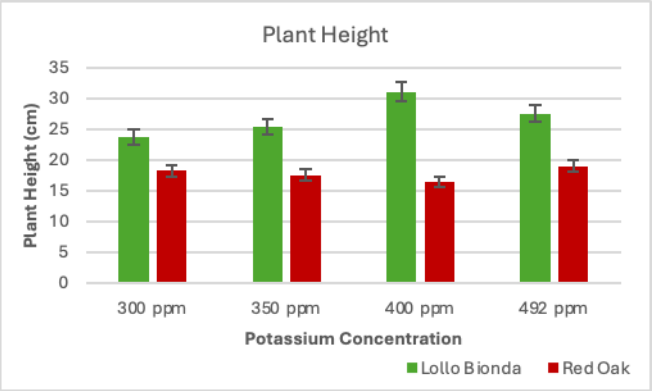

Fig. 4. Average plant height of Lollo Bionda and Red Oak under each K condition. All values are expressed as the mean ± S.E. Statistical analysis was conducted by one-way ANOVA followed by LSD for multiple comparison analysis.

Fig. 5. displays the results of the average fresh weight of the final harvests.

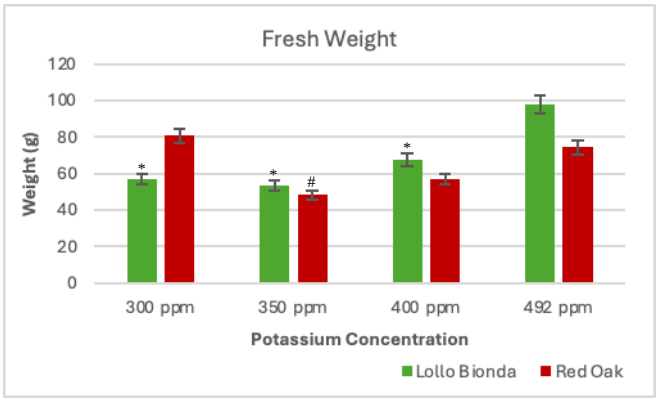

Fig. 5. Average harvested fresh weight of Lollo Bionda and Red Oak under each K condition. All values are expressed as the mean ± S.E. Statistical analysis was conducted by one-way ANOVA followed by LSD for multiple comparison analysis. * represents $p<0.05$ compared to Lollo Bionda 492 ppm control group and # represents $p<0.05$ compared to Red Oak 492 ppm control group

Table I shows the results of the average TCC, TPrC, TPC, and TFC in Lollo Bionda and Red Oak study groups.

TABLE I. RESULTS OF BIOCHEMICAL PARAMETERS

Plant Group	*TCC (g/100g)*	*TPrC (g/100g)*	*TPC (mg GAE/g)*	*TFC (mg QE/g)*
LB-300	0.275	0.489*	0.289	0.633
LB-350	0.233	0.483*	0.321	0.854*
LB-400	0.238	0.241	0.361*	0.791
LB-492	0.269	0.139	0.244	0.512
RO-300	0.235	0.622	0.538	0.964
RO-350	0.252	0.983#	0.960#	2.068#
RO-400	0.202	0.423	0.542	1.374
RO-492	0.195	0.485	0.552	1.342

Statistical analysis was conducted by one-way ANOVA followed by LSD for multiple comparison analysis. * represents $p<0.05$ compared to Lollo Bionda 492 ppm control group and # represents $p<0.05$ compared to Red Oak 492 ppm control group. (LB = Lollo Bionda grown in different concentrations of 300, 350, 400 and 492 ppm, RO = Red Oak grown in different concentrations of 300, 350, 400 and 492 ppm, TCC = Total Carbohydrate Content, TPrC = Total Protein Content, TPC = Total Phenolic Content and TFC = Total Flavonoid Content)

A soilless technique was used in this study since the availability of nutrients in soil is dependent on buffering capacity, moisture, pH and other variables which could limit the plants from absorbing the added potassium [13]. In techniques like hydroponics, pH is constantly maintained and since water has minimal buffering capacity, the plants can absorb the potassium to its full potential [14, 15].

Increased K levels showed a significant increase in average leaf number, leaf area and average plant weight in Lollo Bionda. In terms of plant height, there were no significant differences between the groups in both lettuce varieties. This is consistent with the findings of Hong *et al.* [5], where a significant difference was present in fresh weights and absent in plant heights, across varying K levels. Potassium is necessary for photosynthesis, as it is involved in stomatal conductance and elevated levels of potassium are therefore proven to increase the overall plant growth. It also promotes cell division in meristems and maintains turgor pressure, facilitating plant growth [16]. Potassium regulates mesophyll cell proliferation and expansion which is responsible for the increase in leaf area with increasing K levels [17]. These reasons explain the increase in average leaf number, leaf area and plant weight with the increase in K levels of Lollo Bionda. In contrast, the highest average leaf number, leaf area and plant weight were recorded in lowest K level of 300 ppm in Red Oak. Although the NFT systems were set up in the same greenhouse, the area in which the Red Oak system was placed was exposed to direct sunlight. Some abnormalities in the Red Oak plants were observed during the growth period which was rectified after the greenhouse ceiling was covered to prevent direct sunlight. This could possibly be a reason for the differences in the trends of Lollo Bionda and Oak Red. However, further investigations are required to understand the underlying mechanisms of potassium uptake and its effects on the yield and morphological parameters of the plants.

The carbohydrate content did not show a notable trend with varying potassium levels in both lettuce varieties. As per previous studies, an increase of potassium showed a decrease in soluble monosaccharides such as glucose or fructose, with a concurrent reduction in fresh weight [18]. This is since potassium is involved in photophosphorylation which translocate photo assimilates from source to sink. Therefore, with increasing potassium level, the monosaccharides are converted to structural carbohydrates that increases the biomass of the plant [19]. However, after exceeding a limit of potassium level, there was an increase in the sugars. This was because there was an accumulation of soluble sugars instead of being converted to structural carbohydrate due to reaching a saturation point. In these studies, the ideal potassium level was chosen with the highest fresh and dry mass but low levels of soluble sugars. In our experiment there is a significant increase in fresh mass with increasing potassium level, but the level of soluble sugars (dextrose) didn't have any significant difference. This suggests the fresh mass of the plants could be further increased by increasing the potassium level as the saturation point hasn't reached.

The highest protein levels were observed in 300 ppm treatment group for Lollo Bionda and in 350 ppm treatment group for Red Oak and they were significantly high compared to their respective control groups. With increasing K levels, total protein content has gradually reduced in Lollo Bionda. However, although a specific trend was not observed, Red Oak reported almost double the amount of proteins when compared with Lollo Bionda (Table I). Previous studies have shown protein content increases with increasing potassium levels due to its involvement in protein synthesis [20].

The highest phenol content for Lollo Bionda was observed in 400 ppm treatment group and it was significantly higher than the control group (492 ppm). In Red Oak, the highest phenol content was recorded in 350 ppm treatment group, and it was significantly higher than all other groups. Phenolic level can vary due to the lettuce variety and stress conditions [21]. Red varieties of lettuce naturally have high levels of phenol in comparison to green varieties. According to a previous study done on lettuce, phenol content has not changed with increasing potassium levels [22].

The highest flavonoid content was observed in the 350 ppm treatment group in both Lollo Bionda and Red Oak lettuce and they were significantly high compared to the respective control groups. However, there was no trend in flavonoid levels with increasing potassium levels. Red Oak lettuce showed a significantly higher flavonoid content than Lollo Bionda since red lettuce varieties are naturally high in flavonoids [21]. Consistent with previous studies, flavonoid content in our study did not change with increasing potassium levels [22].

IV. Conclusion

The study revealed that the optimum potassium level for Lollo Bionda lettuce to achieve the ideal physical properties was 492 ppm, and the preferred potassium level to achieve the ideal nutritional content was 300 ppm. The preferred potassium level for Red Oak to achieve the ideal physical properties was 300 ppm and the preferred potassium level to achieve the ideal nutritional content was 350 ppm. The results showing significantly low values of leaf number, leaf area and fresh weight for Red Oak at 350 ppm compared to control could be due to anomalies occurred during the study. Hence, further investigations should be done with more optimized conditions to validate these findings. Overall, it can be suggested that the original K level of 492 ppm in AiGrow™ nutrition solution can be reduced further to obtain a higher and more nutritious lettuce yield.

References

[1] N. Sharma, S. Acharya, K. Kumar, N. Singh, O.P. Chaurasia. "Hydroponics as an advanced technique for vegetable production: An overview," Journal of Soil and Water Conservation, vol. 17, pp 364-71, 2018.

[2] G. Barbosa, F. Gadelha, N. Kublik, A. Proctor, L. Reichelm, E. Weissinger, et al. "Comparison of Land, Water, and Energy Requirements of Lettuce Grown Using Hydroponic vs. Conventional Agricultural Methods", International Journal of Environmental Research and Public Health, vol. 16, pp 68-91, 2015.

[3] O. Voutsinos-Frantzis, G. Ntatsi, I. Karavidas, I. Neofytou, K. Deriziotis, A. Ropokis, et al. "Exploring the Simultaneous Effect of Total Ion Concentration and K:Ca:Mg Ratio of the Nutrient Solution on the Growth and Nutritional Value of Hydroponically Grown *Cichorium spinosum L. Agronomy*", vol. 12, pp 2214, 2024.

[4] M. Wang, Q. Zheng, Q. Shen, S. Guo. "The Critical Role of Potassium in Plant Stress Response", International Journal of Molecular Sciences, vol. 14, pp 7370-90, 2013.

[5] J. Hong, F. Xu, G. Chen, X. Huang, S. Wang, L. Du, et al. "Evaluation of the Effects of Nitrogen, Phosphorus, and Potassium Applications on the Growth, Yield, and Quality of Lettuce (*Lactuca sativa L.*)", Agronomy, vol. 12, pp 2477, 2022.

[6] M. DuBois, K.A. Gilles, J.K. Hamilton, P.A. Rebers, Fred Smith. "Colorimetric Method for Determination of Sugars and Related Substances", Analytical Chemistry, vol. 28, pp 350–6, 1956.

[7] J.H. Waterborg. "The Lowry Method for Protein Quantitation", Springer Protocols Handbooks, pp 7–10, 2009.

[8] S. Chandra, S. Khan, B. Avula, H. Lata, M.H. Yang, M.A. ElSohly, et al. "Assessment of Total Phenolic and Flavonoid Content, Antioxidant Properties, and Yield of Aeroponically and Conventionally Grown Leafy Vegetables and Fruit Crops: A Comparative Study", Evidence-Based Complementary and Alternative Medicine, pp 1–9, 2014.

[9] U.M. Rao. "Phytochemical Screening, Total Flavonoid and Phenolic Content Assays of Various Solvent Extracts of Tepal of *Musa paradisiaca*", Malaysian Journal of Analytical Science, vol. 20, pp 1181–90, 2016.

[10] A.T. Bristy, T. Islam, R. Ahmed, J. Hossain, H.M. Reza, P. Jain. "Evaluation of Total Phenolic Content, HPLC Analysis, and Antioxidant Potential of Three Local Varieties of Mushroom: A Comparative Study Salmerón I, editor", International Journal of Food Science, pp 1–11, 2022.

[11] K.D. Rajesh, S. Vasantha, N.V. Rajesh, A. Panneerselvam. "Qualitative and quantitative phytochemical analysis in four pteridophytes", International Journal of Pharmaceutical Sciences Review and Research, vol 27, pp 408-12, 2014.

[12] C.N.V Sitati, K.O. Ogila, R.W. Waihenya, L.A. Ochola. "Phytochemical Profile and Antimicrobial Activities of Edible Mushroom *Termitomyces striatus*", Evidence-based Complementary and Alternative Medicine : eCAM, pp 3025848, 2021.

[13] P. Marschner, Z. Rengel Z. "Nutrient availability in soils", Marschner's Mineral Nutrition of Plants, pp 499–522, 2023.

[14] M. Ali Al Meselmani. "Nutrient Solution for Hydroponics", Soilless Culture, 2022.

[15] B. Frasetya, K. Harisman, N.A.H. Ramdaniah. "The effect of hydroponics systems on the growth of lettuce", IOP Conference Series: Materials Science and Engineering, vol. 1098, pp 042115, 2021.

[16] J. Sardans, J. Peñuelas. "Potassium Control of Plant Functions: Ecological and Agricultural Implications", Plants, vol. 10, pp 419, 2021.

[17] W. Hu, Z. Lu, F. Meng, X. Li, R. Cong, T. Ren, et al. "The reduction in leaf area precedes that in photosynthesis under potassium deficiency: the importance of leaf anatomy", New Phytologist, vol. 227, pp 1749–63, 2020.

[18] T.C. Barickman, T.E. Horgan, J.R. Wheeler, C.E. Sams. "Elevated Levels of Potassium in Greenhouse-grown Red Romaine Lettuce Impacts Mineral Nutrient and Soluble Sugar Concentrations HortScience", vol. 51, pp 504–9, 2016.

[19] I.H. Shah, W. Jinhui, X. Li, M.K. Hameed, M.A. Manzoor, P. Li, et al. "Exploring the role of nitrogen and potassium in photosynthesis implications for sugar: Accumulation and translocation in horticultural crops", Scientia Horticulturae, vol. 327, pp 112832, 2024.

[20] J. Rawat, N. Pandey, J. Saxena. "Role of Potassium in Plant Photosynthesis, Transport, Growth and Yield", Role of Potassium in Abiotic Stress, pp 1–14, 2022.

[21] A. Galieni, C. Di Mattia, M. De Gregorio, S. Speca, D. Mastrocola, M. Pisante, et al. "Effects of nutrient deficiency and abiotic environmental stresses on yield, phenolic compounds and antiradical activity in lettuce (*Lactuca sativa L.*)", Scientia Horticulturae, vol. 187, pp 93–101, 2015.

[22] W. Sublett, T. Barickman, C. Sams. "The Effect of Environment and Nutrients on Hydroponic Lettuce Yield, Quality, and Phytonutrients. Horticulturae", vol. 4, pp 48, 2018.

Detecting Phosphorus Levels in Paddy (*Oryza sativa*) Using Computer Vision: A Precision Agriculture Approach

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***Abstract*-This study detects the phosphorus level in paddy, *Oryza sativa*, through computer vision to change how manages phosphorus. Many conventional phosphorus status assessment methods of crops are time-consuming, labor-intensive, and out of reach for smallholder farmers. To meet these challenges, the present study aims to develop a computer vision-based system that detects and monitors real-time phosphorus levels by image analysis of the plant leaves. This study involves two significant experiments. The former has investigated the various phosphorus levels on growth attributes such as plant height, root volume, and yield, indicating the optimal application rate of 184 mg of P per pot. Based on the data from the leaf images, phosphorus level classification was done using the CNN model in the second experiment. The CNN model showed 70% accuracy in the case of phosphorus deficiencies, which, though promising for scalability and further optimization, shows how valuable this study is to gain meaningful insights into the application of AI-based technology in nutrient management. This will contribute to more sustainable and efficient agricultural practices, reducing the environmental risk of improper fertilizer use.**

Keywords - Computer vision, phosphorus management, paddy plants, precision agriculture, nutrient monitoring, sustainable farming.

I. INTRODUCTION

Phosphorus is one of the essential nutrients for rice, serving as a participant in all major metabolic processes: photosynthesis, energy transfer, and root development [1]. However, inappropriate phosphorus application triggers both deficiency and excess, reducing yields and causing environmental degradation [2]. Current conventional soil testing needs to be more efficient in monitoring phosphorus variability in real-time, especially for small-scale farmers [3]. This research uses computer vision to monitor phosphorus within paddy plants, a live, non-invasive method and upwardly scalable technique to supplement or replace the conventional methods used today [4]. This is achieved by employing AI and machine learning, particularly CNNs, to address the abovementioned shortcomings regarding phosphorus management by offering farmers a friendlier, more practical, less time-consuming tool [5].

However, phosphorus is essential not only to promote important metabolic activity within the rice plant cells but also, to enhance their growth by stimulating energy accumulation and transfer [6]. Yet the practices of phosphorus applications include its overapplication and deficiency which both reduce yield and cause pollution of soil and water environment [7]. In this respect, the need to improve and develop modern technologies that allow real-time testing on smallholder farms increasingly makes sense [8]. However, more recent research has shown that computer vision technologies constitute a viable substitute, integrated within artificial intelligence and machine learning models. These systems use convolutional neural networks (CNNs), which can measure the phosphorus content of paddy plants and therefore contribute to the improvement of precision agriculture by optimizing time and input costs for the farmers [9].

II. METHODOLOGY

This research is based on a rigid experimental methodology with two significant parts: field

experiments and computer vision system development. The study was conducted at SLTC Research University, Sri Lanka, in an artificially controlled environment to ensure the data's accuracy.

Experiment 1: Effects of Phosphorus on Plant Growth

The present experiment was conducted to study the effect of different phosphorus levels on the growth and yield of paddy plants (Oryza sativa).

A. Design of the experiment

- Plant Material: The variety of rice used was "BG-374," a popular commercial variety under cultivation in Sri Lanka.
- Phosphorus Treatments: Seven phosphorus treatments were applied, namely 0 mg, 61.3 mg, 122.6 mg, 184 mg-optimal control, 245.3 mg, 306.6 mg, and 368 mg per pot.
- Potting and Growth Conditions: Plants were grown in 5-litre pots, each filled with soil, sand, and organic matter. Phosphorus treatments were applied to every pot, while other variables, such as irrigation and sunlight exposure, were kept constant to avoid experimental bias.

B. Data Collection

- Measurements were taken weekly for a total of 12 weeks. Intrinsic measurements included plant height, the number of leaves and tillers, root volume, root length, and panicle length.
- Seeds per panicle, weight of seeds (1000 seeds), percentage of filled and unfilled grain, and other primary yield attributes were measured after harvest.
- Manual tools such as rulers, scales, and measuring cylinders were used to ensure measurement accuracy.

C. Statistical Analyze

- Data were analyzed through one-way ANOVA to determine the statistical significance of phosphorus treatments in plant growth.
- Tukey's post-hoc test was performed to see the comparisons of the treatment groups.
- Regression analysis was performed to determine the relationships between the levels of phosphorus and plant growth/yield metrics.

Experiment 2: Computer Vision-Based Phosphorus Detection

The objectives of this experiment were to devise a computer vision system that could detect phosphorus levels based on the appearance of the plant leaves, especially by employing methods of image processing.

A. Image Collection

- Equipment: Images of paddy leaves for the different growth stages were taken using a 48-megapixel mobile camera.
- Image Acquisition Methodology: Images were taken daily from the plants' top, left, and right sides to capture all visual features exhibited by leaves. Plants were set on a white background to reduce disturbance or reflection.

B. Data Preprocessing

- Leaf Features: Color and texture, with particular emphasis on green color intensity variations related to phosphorus levels.
- Data Labelling: Each image was tagged with metadata, including phosphorus treatment, plant ID, and time of capture, allowing for systematic analysis.

C. Model Development

- A convolutional neural network model was designed and trained on the captured images. The CNN was supposed to classify the phosphorus level by the visual features of the leaves.

D. Color Space Conversion

- The model used the YMCK color model as a subtractive color model to identify subtle shades of green that represented deficiency or excess phosphorus.

E. Testing and Validation

- PSP used 70% of the image data to train the CNN model and held the remaining 30% for validation.
- Results were calculated based on the confusion matrix to test the correct classification of phosphorus, especially when the phosphorus levels were either extremely high or very low.

III. RESULTS

In Experiment 1, the effects of seven levels of phosphorus application, from deficiency to surplus levels, were studied. Fig. 1 depicts the plant height against phosphorus treatment levels. From the graph, it is evident that the height peaked at 184 mg per pot and decreased significantly both below and over this level. These plants treated with 184 mg of phosphorus had the maximum height, number of tillers, and overall yield. For instance, the bar graph clearly illustrates that this group outperformed the group with 0 mg and 368 mg application of phosphorus, where stunted growth and nutrient stress were apparent. This confirms the hypothesis that applying balanced phosphorus is crucial to achieving optimum growth. Also, the root length represented in Fig. 2 is significantly higher in the case of 184 mg, thus justifying that this amount of phosphorus is optimum.

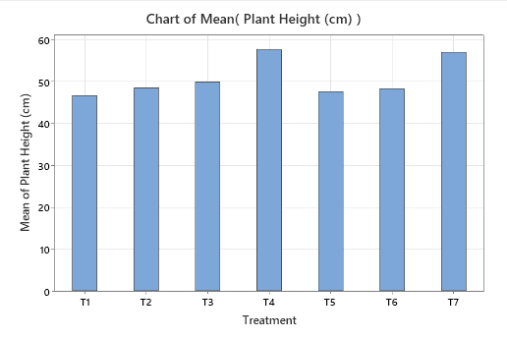

Fig. 1: Effect of phosphorus treatments on plant height

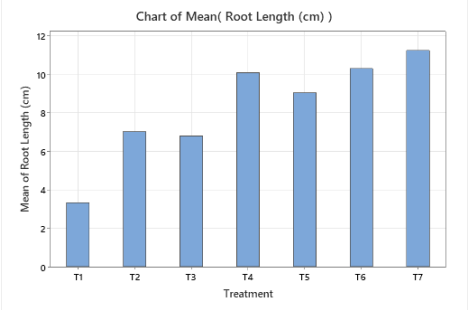

Fig. 2: Effect of phosphorus treatments on root length

Developing and testing the CNN model in detecting phosphorus in paddy leaves were the central issues of analysis in Experiment 2. The model performance of the CNN is presented in a visual format in the form of a heat map in Fig. 3. Looking at the heatmap of the confusion matrix, the more extreme conditions of phosphorus being very deficient or very excessive are expressed with the darker diagonal boxes of the matrix. However, it points toward where the model struggled, mainly around the middle areas with non-extreme phosphorus levels, where misclassifications occur. This is further substantiated by the fact that several plant images with medium phosphorus levels were identified as deficient or excessive, indicating the necessary refinement of the model.

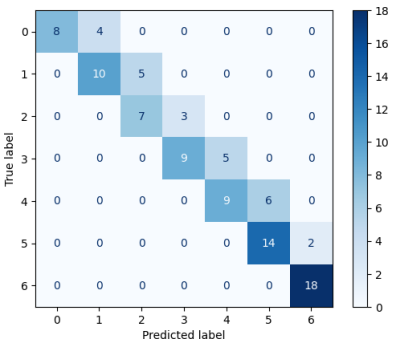

Figure. 3: The confusion matrix of the proposed model

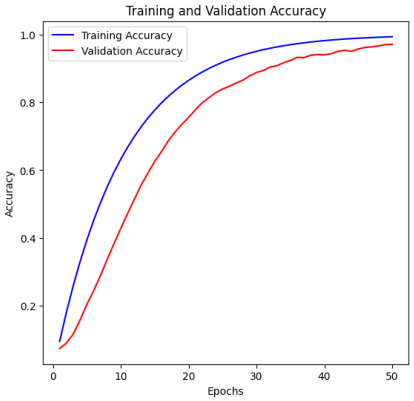

Fig. 4: Training and validation accuracy curves obtained for the proposed model

Finally, Fig. 4 of the Training and Validation Accuracy Curve depicts the performance of the CNN model for training during several epochs. From the curve, the training accuracy reached approximately 81%, while the validation accuracy level stopped growing at approximately 72%. That means the model has learnt to classify the phosphorus level well on the training data. Still, there might have been some overfitting, as evidenced by the graph's gap in training and validation accuracies. This curve helps illustrate how the model performance could improve with more data and fine-tuning.

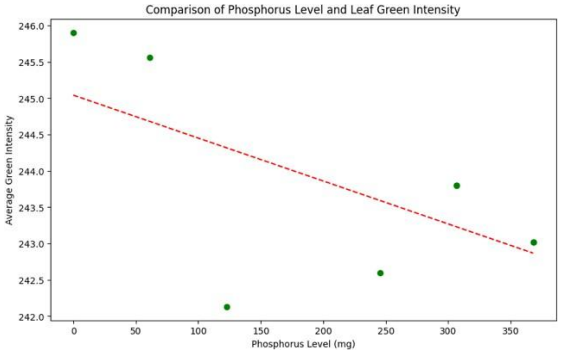

Figure 5: Comparison of phosphorus level and leaf green intensity

Fig. 5, concerning manually detecting phosphorus and the CNN model, is also remarkable. CNN-based detection was significantly quicker and more consistent than the manually done ones. Such a chart comparing the results would highlight differences between traditional soil testing and image-based detection, hence a view on time saved and consistency achieved by automation.

The CNN model that was used during Experiment 2 showed potential in classifying phosphorus levels in paddy plants based on images. The model had a mean training accuracy of 0.81 and a validation accuracy of 0.72; however, the validation loss of 1.14 was high, indicating areas for improvement, particularly for model generalization. The analysis of the confusion matrix indicated that a good classification accuracy was achieved for treatments T6 and T7 for the highest phosphorus level, although some errors were recorded in the classification of closely related phosphorus treatments such as T2 and T3. The model's precision for T6 and T7 was 0.75 and 0.78, respectively, while the recall values were 0.79 and 0.82. The F1 scores that were achieved for these treatments were 0.77 and 0.80, which means there was a strong overall performance, although there is room for further improvement as well.

IV. CONCLUSION

For a paddy farming, this study showed conclusively that computer vision and machine learning using Convolutional Neural Network (CNN) techniques can assist in controlling phosphorus levels efficiently. The ideal phosphorus concentration of 184 mg per pot was determined to have a beneficial effect on improving plant height, root and yield parameters. These point conclusions were validated by visual figures that convincingly demonstrated the need for efficient phosphorus management practices to enhance the plant performance. In this research, the CNN model used for this study had a validation accuracy of 72% which is significantly good for a phosphorus detection system. The two extremes of phosphorus levels were well predicted but more still needs to be done for the intermediate phosphorus levels. These findings indicate that modeling can be improved through better techniques for feature extractions in order to improve performance and predictive accuracy. In the end, the research highlights the advantages of implementing artificial intelligence and computer vision in nutrient management in agriculture settings. The two technologies do not only offer timely accurate phosphorus monitoring on-site but also help in the practice of agriculture in a more sustainable and efficient way. This work provides a very good starting place for subsequent investigators to modify the CNN model and apply it to other crucial nutrients, such as nitrogen and potassium, thus contributing to the development of precision agriculture.

V. ACKNOWLEDGMENT

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VI. REFERENCES

[1] G. Eason, B. Noble, and I. N. Sneddon, "On certain integrals of Lipschitz-Hankel type involving products of Bessel functions," *Phil. Trans. Roy. Soc. London*, vol. A247, pp. 529–551, Apr. 1955.

[2] J. Clerk Maxwell, *A Treatise on Electricity and Magnetism*, 3rd ed., vol. 2. Oxford: Clarendon, 1892, pp.68–73.

[3] I. S. Jacobs and C. P. Bean, "Fine particles, thin films and exchange anisotropy," in *Magnetism*, vol. III, G. T. Rado and H. Suhl, Eds. New York: Academic, 1963, pp. 271–350.

[4] 4M. Young, *The Technical Writer's Handbook*. Mill Valley, CA: University Science, 1989.

[5] N. Ahmad, "Advanced methodologies in phosphorus monitoring," *Int. J. Agric. Res.*, vol. 42, no. 4, pp. 201-210, 2017.

[6] P. Conley, "Phosphorus impact on rice yield," *Agric. Sci.*, vol. 55, pp. 212–230, 2020.

[7] D. Razaq, "Soil nutrient analysis for precision farming," *Env. Impact J.*, vol. 45, pp. 315–329, 2018.

[8] R. Daw, "Challenges in phosphorus sustainability," *AgriTech Review*, vol. 12, pp. 45-60, 2021.

[9] S. Nanda, "Rice cultivation and phosphorus toxicity," *Plant Physiology*, vol. 33, pp. 350-367, 2019.

Evaluating Soil Properties in Coconut-Based Agroforestry Systems Intermediate Zone of Sri Lanka

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***Abstract*— Coconut (Cocos nucifera L.) is cultivated worldwide because of its multiple uses. Based on the morphological characteristics of the coconut tree, when coconut is grown as a mono-crop, land use efficiency is very low. This study aimed to assess soil quality in various coconut-based agroforestry systems in the Makandura research station of the Coconut Research Institute, of Sri Lanka situated in a low country Intermediate Zone. Eight different intercropping systems under mature coconut plantations (>40 years) were assessed. Soil samples were collected from 0-45 cm depths using a random sampling technique with five replicates per system. Key soil physical and chemical properties were analyzed. Statistical analyses were performed using the MINITAB 19 version. Results showed significant differences among agroforestry systems, with sweet potato and cocoa cultivation showing notably positive impacts on soil health. The pineapple + coconut intercropping system showed mixed results. Coconut monoculture, while beneficial in some aspects, demonstrated potential for soil degradation without proper management. The findings of this research provide valuable insights into the impact of different agroforestry practices on soil quality in coconut plantations.**

Keywords---Cocos nucifera L., Agroforestry, Soil Quality, Intercropping, Low Country Intermediate Zone

I. INTRODUCTION

Coconut (*Cocos nucifera* L.) is one of the major plantation crops in Sri Lanka. Sri Lanka is currently one of the top exporters of coconuts in the world, having been involved in the coconut industry since the British colonial period (19th century). Coconut is a globally important perennial crop known as the 'tree of life' in many communities worldwide. Coconut-based agroforestry systems are land-use systems in tropical areas that integrate coconut trees with additional crops often including annuals as well as perennials. Most coconut lands are managed as monocultures, resulting in relatively low returns per unit area for farmers compared to their potential in more intensified land use systems. However, in recent years, there has been a growing interest in sustainable and diversified farming systems, including coconut-based intercropping practices. The major crops grown in association with coconuts in the intermediate zone of Sri Lanka can be listed as Cocoa (*Theobroma cacao*), Cassava (*Manihot esculenta*), Sweet potato (*Ipomea batatas*), Dragon fruit (*Selenicereus undatus*), Banana (*Musa paradisiaca*), Mango (*Mangifera indica*), Rambutan (*Nephelium lappaceum*) [1].

Soil health has been one of the critical deciding factors in the success or failure of human civilization. Different vegetation types can significantly alter the physical, chemical, and biological aspects of the soil [2]. They can have long-term effects on soil characteristics [3], and these changes may be used as a crucial tool to evaluate the changes in soil quality [4]. Therefore, Soil Quality (SQ) assessments are necessary to understand the state of the soil and create more effective management strategies. Many studies on SQ indexing focus on short-term effects, but there is limited research on the long-term impacts of land use change on SQ. It is crucial to comprehend the long-term viability natural and sustainability of different coconut-based agroforestry systems in the intermediate zone of Sri Lanka. It is crucial to comprehend the long-term viability and sustainability of different coconut-based agroforestry systems.

II. MATERIALS AND METHODS

A. Description of the study area

The study was conducted from 2023 December to 2024 September which is conducted Makandura Research Station Low Country Intermediate Zone (AER IL).
The study was conducted under a mature coconut (>40 years) plantation. Makandura Research Station belongs to the intermediate zone, AER IL 1a, the major soil group was Red yellow Podzolic soil with strongly mottled subsoil, and mean annual rainfall is >1400 mm [5].

B. Experimental Design

Random sampling technique was used to collect samples from eight land use systems with 0-45cm depths and five replicates. Coconut monoculture and seven different multiple cropping systems were selected.

Table 1: Selected treatments

Intermediate zone
T1-Coconut monoculture
T2-Cocoa + Coconut
T3-Dragon Fruit + Coconut
T4-Mango + Coconut
T5-Manioc + Coconut
T6-Pineapple + Coconut
T7-Rambutan + Coconut
T8-Sweet Potato + Coconut

C. Soil Sampling and preparation

Soil samples were randomly collected from each experimental site. Soil auger was employed to extract soil specimens. In each land use system, soil samples were collected from five random locations. The representative soil sample collected was divided into two subsets. One subset of the sample was air-dried and passed through a 2 mm sieve. The samples were stored in a moisture-free environment for further analysis.

D. Soil Analysis

Soil samples were analyzed at both the Agronomy and Soil Divisions of the Coconut Research Institute. The physical, chemical, properties of soil samples were determined using standard analytical procedures. The soil moisture content, bulk density and porosity were analyzed. Soil pH and electrical conductivity (EC) were measured using a pH meter and a conductivity meter in a 1:2 soil-to-water ratio [6]. The soil organic carbon (SOC) was estimated using the wet digestion method [7]. The soil total nitrogen (N) was measured using the Kjeldahl procedure. Phosphorus (P) was determined by the alkaline ammonium acetate extractant method [6]. Soil-available potassium, calcium, and magnesium content was determined using an atomic absorption spectrophotometer.

E. Data Analysis

MINITAB 19 version was used for statistical analyses. The normality of all measured parameters was tested using the normality test and outlier test. Next descriptive statistics of measured parameters were collected. Finally, the mean values of data were statistically compared using One-Way Analysis of Variance (ANOVA) at 5% significance and Turkey's pairwise comparison test.

III. RESULTS AND DISCUSSION

A. Effect of land use systems on soil indicators

1) Soil chemical properties.

Sweet potato, coconut monoculture, mango, and cocoa systems exhibited the highest pH values, ranging from 5.27 to 5.42. Similarly, the high pH in coconut monoculture (5.40) might have been attributed to the decomposition of coconut husks and fronds, which were often left in the field. In stark contrast, dragon fruits exhibited the lowest pH (4.77), indicating significantly more acidic conditions. While dragon fruits tolerated a pH range of 5.5 to 6.5. The intermediate pH group included rambutan, pineapple, and manioc, with pH values ranging from 5.03 to 5.13. Among the cropping systems, pineapple (53.01), dragon fruits (51.46), and rambutan (52.19) exhibited the highest mean EC values. On the other hand, mango (29.19) and coconut monoculture (32.19) had relatively lower mean EC values. Among the cropping systems, sweet potato exhibited the highest mean organic carbon value (1.19), indicating substantial organic matter accumulation. This high organic carbon content could enhance soil fertility, improve soil structure, and increase water retention capacity, contributing to overall soil health and productivity. Rambutan (0.96) and manioc (0.83) also showed relatively high mean organic carbon levels, indicating favorable conditions for organic matter accumulation. In contrast, coconut monoculture (0.69), cocoa (0.72), mango (0.73), and pineapple (0.66) exhibited moderate values. Pineapple exhibited the highest mean available P content (25.45%), suggesting higher phosphorus availability compared to other cropping systems. Dragon fruits (9.61%), rambutan (10.05%), and sweet potato (12.79%) had relatively high mean available P values, indicating moderate levels of plant-available phosphorus in the soil under these cropping systems. Cocoa (3.39%) and mango (3.44%) had the lowest mean available P contents among the cropping systems studied, indicating relatively low levels of plant-available phosphorus in the soil under these cropping systems. Sweet potato exhibited the highest mean K content (0.22%), followed by pineapple (0.19%), indicating potentially higher levels of plant-available potassium in the soil under these cropping systems compared to others.

Rambutan (0.137%) had a moderately high mean K content, lower than sweet potato and pineapple but higher than several other cropping systems. Coconut monoculture (0.07%), cocoa (0.07%), mango (0.07%), and manioc (0.05%) exhibited mean K contents in the lower range, indicating relatively lower levels of plant-available potassium in the soil under these cropping systems. Sweet Potato, with a mean Ca content of 0.67%, also showed a substantial positive impact on soil calcium. Similarly, Rambutan, exhibiting a mean Ca content of 0.56%, supports the notion that perennial fruit trees can significantly contribute to soil nutrient status through the continuous input of organic residues. Manioc (0.53%), pineapple (0.51%), dragon fruits (0.49%), and mango (0.46%) display moderate levels of soil Ca content.

Table 2: Treatment Effect on chemical and Physical properties

Cropping System	MC (% DW Basis)	BD (g/cm^{-3})	Porosity%	pH	EC (Ms/cm)	OC %	Available P %	K %	Ca %	Mg %	CEC	N %
Coconut monoculture	8.99 a	1.57a	40.83b	5.40a	32.19bc	0.69ab	5.76b	0.07b	0.38d	0.39a	4.06b	0.05c
Cocoa	10.41 a	1.52ab	42.53ab	5.28a	49.12a	0.72ab	3.39 b	0.07b	0.69a	0.41a	5.21a	0.05bc
Dragon Fruits	9.18a	1.43ab	46.31ab	4.77b	51.46a	0.53b	9.61ab	0.034b	0.49cd	0.434a	4.24b	0.04c
Mango	9.71a	1.56a	41.01b	5.34a	29.19c	0.73ab	3.44 b	0.07b	0.46cd	0.45a	4.21b	0.08ab
Manioc	9.92a	1.45ab	45.39ab	5.03ab	44.58ab	0.83ab	6.31 b	0.05b	0.53bcd	0.42a	4.15b	0.09a
Pineapple	9.84a	1.50a	41.88b	5.08ab	53.01a	0.66b	25.45 a	0.19a	0.51cd	0.39a	4.57ab	0.07ab
Rambutan	9.42a	1.40ab	47.04ab	5.13ab	52.19a	0.96ab	10.05 ab	0.13ab	0.56abc	0.39a	4.29b	0.08ab
Sweet Potato	9.43a	1.35b	48.95a	5.42a	47.53a	1.19a	12.79 ab	0.22a	0.67ab	0.52a	4.50ab	0.04c
P- Value	0.205	0.001	0.001	0	0	0.009	0.002	0	0	0.709	0	0
CV	12.03	9.19	11.58	6.83	28.77	49.33	132.98	95.05	26.46	35.62	13.53	37.71
SD	1.157	0.1358	5.123	0.354	12.92	0.3892	12.77	0.099	0.1419	0.1519	0.5955	0.00268

The mean magnesium (Mg) content in the soil varied among different cropping systems, with Sweet Potato showing the highest mean Mg content at 0.52%, indicating its strong potential to enhance soil Mg levels. Mango and dragon fruits also contributed significantly to soil Mg, with mean contents of 0.45% and 0.44%, respectively. Manioc (0.42%) and cocoa (0.41%) showed moderate Mg content, suggesting a reasonable influence on soil Mg enrichment. Rambutan (0.39%) and pineapple (0.39%) exhibited slightly lower Mg content, while coconut monoculture had the lowest mean Mg content at 0.39%, highlighting its relatively minimal effect on increased soil Mg levels.

The study revealed that the mean CEC values varied significantly among the different cropping systems. Cocoa cultivation exhibited the highest mean CEC value of 5.21, indicating its remarkable potential for enhancing soil fertility and nutrient retention. In contrast, coconut monoculture (4.06) and manioc (4.15) exhibited slightly lower mean CEC values compared to the other cropping systems

1) Soil physical properties

The table 2 illustrates the moisture content in the soil of the Coconut Square expressed as a percentage on a dry weight (DW) basis, in Makandura estate for various cropping systems. The analysis showed that there was statistically significant effect between the CS ($P<0.05$) for MC. The coconut monoculture system exhibited the lowest mean moisture content of 8.99% potentially due to the extensive root system and high-water uptake capacity of coconut trees. In contrast, cocoa cultivation demonstrated a higher mean moisture level of 10.41%, suggesting differences in water requirements and soil moisture dynamics between these two cropping systems.

Coconut monoculture and mango orchards exhibited the highest bulk densities 1.57% and 1.56%, respectively, suggesting severe soil compaction. Pineapple cultivation also showed a high bulk density (1.50%), indicating significant soil compaction. Intermediate bulk densities were observed in cocoa (1.52%), dragon fruits (1.42%), manioc (1.45%), and rambutan (1.40%) cropping systems. Sweet potato cultivation stood out with the highest soil porosity (48.95%). Following closely were rambutan (47.04%) and dragon fruits (46.31%), both exhibited high porosity values. Manioc (45.39%) and cocoa (42.53%) displayed moderate porosity levels, indicating a balance between compaction and aeration. In contrast, coconut monoculture (40.83%), mango (41.01%), and pineapple (41.88%) exhibited the lowest porosity values, indicatingmorecompactedsoil.

IV. CONCLUSION

The research findings indicate that the coconut-based agroforestry systems have a substantial long-term impact on the physical, and chemical characteristics of coconut plantations in the Intermediate Zone of Sri Lanka. The SQ was evaluated for eight land use systems. Three soil physical parameters (MC, Bulk Density, Porosity) and nine soil chemical parameters (pH, OC, Available P, K, Ca, Mg, CEC, Total N, and EC were selected. This study reveals the significant impact of different cropping systems on soil properties, highlighting both the benefits and challenges associated with various crops. Sweet potato emerges as particularly beneficial for soil health, while coconut monoculture shows potential for degradation without proper management. Fruit trees offer sustainable options, pineapple systems require careful handling, and cocoa demonstrates positive attributes like high CEC. Based on these findings, the research recommends diversifying land use, integrating soil-improving crops like sweet potato, implementing conservation practices in monocultures, and exploring agroforestry or mixed cropping systems. Ultimately, the study underscores the importance of tailored soil management strategies, suggesting that a nuanced understanding of crop-soil interactions can guide farmers and land managers in optimizing soil health, productivity, and long-term agricultural sustainability.

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VI. REFERENCES

[1] Nuwarapaksha, T., Udumann, S., Dissanayaka, D., Dissanayake, D., & Atapattu, A. J. (2022). Coconut based multiple cropping systems: An analytical review in Sri Lankan coconut cultivations. *Circular Agricultural Systems*, *2*(1), 1–7. https://doi.org/10.48130/cas-2022-0008

[2] Tauqeer, H. M., Turan, V., Farhad, M., and Iqbal, M. (2022). "Sustainable agriculture and plant production by virtue of biochar in the era of climate change" in Managing plant production under changing environment. Eds. M. Hasanuzzaman, G. J. Ahammed and K. Nahar (Singapore: Springer), 21–42.

[3] Li, H., Liao, X., Zhu, H., Wei, X., and Shao, M. (2019). Soil physical and hydraulic properties under different land uses in the black soil region of Northeast China. *Can. J. Soil Sci*. 99, 406–419. Doi: 10.1139/cjss-2019-0039

[4] Liu, D., Huang, Y., An, S., Sun, H., Bhople, P., and Chen, Z. (2018). Soil physicochemical and microbial characteristics of contrasting land-use types along soil depth gradients. *Catena* 162, 345–353. Doi: 10.1016/j.catena.2017.10.028

[5] Punyawardena, B.V.R., & Wickramasinghe, W.M.A.D.B. (2003). Mainstreaming Climate Change Adaptations into Developmental Planning, Sri Lanka, 2-9.

[6] Jackson, M. L. (2005). *Soil chemical analysis: advanced course.* Madison, WI: UW Madison Libraries Parallel Press.

[7] Jackson, M. L. (1967). *Soil chemical analysis*. Prentice Hall of India Pvt. Ltd., New Delhi, 498.

Developing an Effective Vegetative Propagation Method for Commercial Cultivation in Gurmar Plant *(Gymnema sylvestre)*

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***Abstract* – Gurmar (*Gymnema sylvestre*) is an uncommon Ayurvedic medicinal plant with immense medicinal properties. It can be classified as a perennial woody vine. That grows in the tropical forests of central, western, and southern India and the tropical regions of Africa, Australia, and China. This vine is widely used in indigenous medicine in the treatment of diabetes. As it is a rare plant with valuable medicinal properties that can treat other diseases besides diabetes, it is essential to obtain optimum and high-quality yield of Gurmar. However, there is still no specific cost-effective vegetative propagation method for Gurmar. Therefore, this study aimed to introduce a cost-effective vegetative propagation method to obtain optimal and sustainable production. The study consisted of 3 stem cutting types of *G. sylvestre* (softwood, semi-hardwood, and hardwood) raised in 6 different potting media (sand, topsoil, coir dust, sand+coir dust, top soil+coir dust, sand+top soil+coir dust) and treated with hormones (Indole-3-Butryric Acid (IBA) 0.31% (CLONEX) and without hormones. The study aimed at the vegetative growth of the plants. The experiment was carried out in a three-factor factorial design with each treatment combination thirty-six (6 x 3 x 2) with ten replicates of *G. sylvestre* cuttings. The whole amount of single-type vegetative propagators is 360 (per 10 replicates). To analyze the data of Number of leaves, Number of new shoots, Root length, new shoot length, and Root volume 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. Significant differences were separated by Tukey's multiple range tests with a 5% level of probability. The survival rate percentage and growth rate of Gurmar cuttings at 12 WAP were evaluated. According to the results, the best survival rate percentages or significantly the highest growth rate were T15 (hardwood, with hormone, coir dust), T27 (semi-hardwood, without hormone, coir dust), and T33 (hardwood, without hormone, coir dust). According to the results, coir dust potting media was in treatments T15, T27, and T33, which showed the highest growth. This experiment further confirms coir dust potting media that is most suitable for the growth of the Gurmar plant. This finding can be developed for further research i.e. T33 treatment can be used effectively in the maintenance of large-scale *G. sylvestre* plantations in the wet zone of Sri Lanka to obtain higher yields.**

Keywords - Gymnema sylvestre, vegetative propagation, Indole-3-Butyric Acid

I. INTRODUCTION

Gurmar plant is a plant with valuable medicinal properties, it is a rare ayurvedic plant species that is not popular among humans. It is also known by the alternative names "Sugar Destroyer" or "Gudmar". The Gurmar plant belongs to the " Apocynaceae " family. Native to tropical forests of central, western, and southern India and in the tropical regions of Africa, Australia, and China, this vine is a plant of high medicinal value that is useful in treating chronic diabetes, which can mainly affect humans [1]. All parts of this plant like bark, roots, leaves, and flowers are full of medicinal properties. *Gymnema sylvestre* can be called one of the plants with strong anti-diabetic properties. The active principle of this plant is the complex mixture of gymnemic acids in the leaves, which reduces blood sugar levels. Gymnemic acid is the main active chemical component

isolated from *G. sylvestre* [2]. Therefore, it is confirmed that this *G. sylvestre* can be introduced as a miracle plant with anti-diabetic potential. In addition, this plant is rich in bioactive compounds such as stigmasterol, quercitol, gymnamine, lupeol, gurmarin, and gymnemagenin[3]. Gymnemic acids have anti-diabetic, sweetener, and anti-inflammatory activities. It increases the production of insulin in the blood and prevents the absorption of sugar molecules in the intestine, reducing the metabolic effects of sugar. This plant has earned the nickname "Sugar Destroyer" due to its unique ability to temporarily suppress the taste of sweets. Currently, there is a huge demand for this plant in the local and international markets. As such, the plant is at risk of extinction due to increased demand and destructive harvesting. Moreover, this plant species is facing the threat of extinction due to the unlimited collection of raw materials for the pharmaceutical industry used for the production of medicines for diabetes, asthma, eye disorders, etc. Considering these facts, to start the cultivation of the *G. sylvestre* plant on a large scale to meet the increasing demand, it is essential to increase the growth rate of the *G. sylvestre* plant and obtain high quantity and quality plant yield. Due to this, the purpose of this experiment was to prepare a proper cost-effective vegetative propagation method to improve the growth rate of this plant which can be used to obtain effective and sustainable harvest in the wet zone of Sri Lanka.

II. METHODOLOGY

This experiment was conducted at a Polytunnel from November 2022 to May 2023 at SLTC Research University (6.8557° N, 80.0926° E, and 27 m above mean sea level, located in the Low country Wet zone (WL1a)) Ingiriya Road, Padukka, Sri Lanka. Firstly, a stock of *G.sylvestre* mother plants was maintained at SLTC Research University premises from November 2022 to carry out this research. The mother plant stock aims to obtain cuttings for cost-effective vegetative propagation. The three-week-old plants were purchased from a certified, local nursery. The plants were established in black pots and a mixture of topsoil, and sand was used as potting media for this plantation. Also, chemical fertilizers (Urea, Triple Super Phosphate, and Vermicompost) were used as fertilizers. I started the propagation trail experiment on 14th February of 2023. It helped to figure out which treatment to go with the appropriate potting media, cutting type, and propagation method. 360 polythene bags of 10 cm width and 22 cm – 20 cm height are prepared. And the lower end of the transparent polybags should be sealed well to avoid dehydration. Thirty-six treatment combinations (6×3×2) were used. Here, cuttings under 3 types, softwood cuttings, semi-hardwood cuttings and hardwood cuttings (cuttings taken from the mother plant stock were used), treated with Indole-3-Butryric Acid (IBA) (CLONEX) and without hormones in 6 potting media that's sand, topsoil, coir dust, sand + coir dust, topsoil + coir dust, sand + topsoil + coir dust potting media was done in a single vegetative propagator method. After that potting media should be added to those bags as prescribed. Here, mix P4, P5 in a 1:1 ratio and P6 in a 1:1:1 ratio in potting media. *G. sylvestre* cuttings were obtained with 12-15cm length, three nodes, and between 1-3 leaves. The basal ends of the cuttings were cut angularly and treated with hormone concentrates before planting in the potting medium. They were dipped in 0.3% IBA rooting hormone for 10 minutes and then planted in propagators at a depth of 2.5 mm. Then the upper ends of the polythene bags are tied well with the help of rubber bands. And, all propagators proceeded to pierce. Then all the propagators (replicates 360) were placed inside the polytunnel according to the order of treatment. Propagators were opened and a fine spray of water was applied every week from the day of planting on Tuesday morning.

The reading here was taken 12 WAP. The parameters obtained were the number of shoot length (cm), root length (cm), number of leaves, number of new shoots, root volume (cm^3), and number of dead cuttings and germinated cuttings. The experiment was laid out in a three-factor factorial design with 10 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. Survival Rate of Gurmar Cuttings

The effect of cutting types, potting media, and rooting hormones was identified at 8 WAP. There, the highest survival rate of 60% was observed in three treatments, hardwood, with hormone, coir dust (T15), semi-hardwood, without hormone, coir dust (T27), and hardwood, without hormone, coir dust (T33) (Table I). Also, a 40% survival rate was shown with semi-hardwood, with hormone, sand (T7), and semi-hardwood, with hormone, coir dust (T9) treatments. Only the measurements from these five treatments were considered for further analysis.

B. Growth Parameters of Gurmar Cuttings

After 12 WAP, there were no significant differences among the treatments for the growth rate significantly. However, a considerably higher number of leaves and shoots were observed with the treatment of hardwood, without hormone and coir dust (T33) (18.67±3.25 cm and 2.83±0.749 cm respectively). A similar trend could be observed with the shoot length, root length, and root volume where the same treatment resulted in a mean of 15.25 ± 1.30, 7.017 ± 0.58, 0.400 ± 0.0894 during 12 WAP respectively (Table II).

In this experiment, according to the results found, significantly higher growth parameters were given by T33 treatment. In addition, T33 treatment shows a significantly higher survival rate percentage.

IV. DISCUSSION

The aim was to test the effectiveness of using different combinations of different growth media, cutting types, and hormones to improve the rooting of *G. sylvestre*. The analysis of the experiment conducted to introduce a cost-

effective vegetative propagation method using 3 cutting types, hormones, and 6 potting media showed that T15 (Hardwood, with hormone, coir dust), T27 (Semi-hardwood, without hormone, coir dust*)* and T33 (Hardwood, without hormone, coir dust) are most outstanding treatments because they showed the highest survival rate. Accordingly, the results showed that semi-hardwood and hardwood cuttings performed better in terms of germination and rooting [4]. Among them, the roots were better without growth hormone [5]. In all treatments, coir dust media is more suitable for plant and root growth than other potting media. Meanwhile, the mixture of semi-hardwood cuttings and coir dust or sand with hormone treatment also shows a significant trend. The effect of various media on the performance of cuttings is closely related to temperature and water contact. A medium temperature of 25-26 °C in the morning and 27-30 °C in the afternoon can improve germination and rooting.

Research has also confirmed the essential role of auxin in the rooting and root formation of cuttings. Auxin has an effect on plant growth rate and improves the rooting rate of cuttings. Plants naturally produce auxin in shoots and young leaves, but artificial auxin is used to prevent cutting death and to ensure successful rooting of cuttings [6]. Different auxin and planting bed treatments had a significant effect on grape rooting i.e. application of 4000 mg/l IBA resulted in positive results of root number, root length, and root fresh and dry weight parameters [7]. Applying IBA significantly affected the rooting rate of single-node leaf cuttings of *Shorea leprosula* obtained from 10-month-old potted plants.

TABLE I. EFFECT OF CUTTING TYPES, ROOTING HORMONES, AND POTTING MEDIA ON SURVIVAL RATE OF GURMAR CUTTINGS

Treatment	Combination	Survival Rate (%)
T1	Softwood, with hormone, sand	20
T2	Softwood, with hormone, topsoil	10
T4	Softwood, with hormone, sand+coir dust	10
T5	Softwood, with hormone, topsoil+coir dust	10
T7	Semi-hardwood, with hormone, sand	40
T8	Semi-hardwood, with hormone, topsoil	10
T9	Semi-hardwood, with hormone, coir dust	40
T10	Semi-hardwood, with hormone, sand+coir dust	10
T12	Semi-hardwood, with hormone, sand+top soil+coir dust	10
T14	Hardwood, with hormone, topsoil	10
T15	Hardwood, with hormone, coir dust	60
T17	Hardwood, with hormone, topsoil+coir dust	30
T18	Hardwood, with hormone, sand+top soil+coir dust	20
T19	Softwood, without hormone, sand	20
T20	Softwood, without hormone, topsoil	20
T23	Softwood, without hormone, topsoil+coir dust	10
T26	Semi-hardwood, without hormone, topsoil	10
T27	Semi-hardwood, without hormone, coir dust	60
T29	Semi-hardwood, without hormone, topsoil+coir dust	10
T30	Semi-hardwood, without hormone, sand+top soil+coir dust	10
T31	Hardwood, without hormone, sand	10
T32	Hardwood, without hormone, topsoil	10
T33	Hardwood, without hormones, coir dust	60
T35	Hardwood, without hormone, top soil+coir dust	10
T36	Hardwood, without hormone, sand+top soil+coir dust	30

TABLE II. EFFECT OF SHOOT LENGTH, ROOT LENGTH, NUMBER OF LEAVES, NUMBER OF SHOOTS, AND ROOT VOLUME ON GROWTH RATE OF GURMAR CUTTINGS

Treatment	Shoot Length (cm)	Root Length (cm)	Num. of Leaves	Num. of Shoot	Root Volume (cm^3)
T7 (Semi-hardwood, with hormone, sand)	14.85 ± 0.811[a]	5.375 ± 0.675[a]	8.00 ± 2.48 [a]	1.500 ± 0.500 [a]	0.200 ± 0.000 [a]
T9 (Semi-hardwood, with hormone, coir dust)	14.50 ± 1.32[a]	4.35 ± 1.28 [a]	9.750 ± 0.854 [a]	0.750 ± 0.250 [a]	0.175 ± 0.0250 [a]
T15 (Hardwood, with hormone, coir dust)	15.067 ± 0.840 [a]	6.90 ± 1.27 [a]	14.83 ± 1.62 [a]	2.667 ± 0.422 [a]	0.283 ± 0.0654 [a]
T27 (Semi-hardwood, without hormone, coir dust)	15.05 ± 1.00 [a]	5.967 ± 0.668 [a]	11.33 ± 2.44 [a]	1.667 ± 0.333 [a]	0.300 ± 0.0447 [a]
T33 (Hardwood, without hormone, coir dust)	15.25 ± 1.30 [a]	7.017 ± 0.58 [a]	18.67 ± 3.25 [a]	2.833 ± 0.749 [a]	0.400 ± 0.0894 [a]

A range of IBA doses (0, 20, 40, 60, and 80 µg IBA per cutting) were tested and 20 µg per cutting was found to be best with 70% of cuttings rooted within 12 weeks, while higher doses revealed lower rooting success [8]. The results of this research also confirm that the rooting percentage is higher in *G. sylvestre* cuttings planted with hormones (Table I). The combinations of BAP and 2, 4-D hormones in an artificial medium when tissue culture techniques were given significantly higher amounts of callus masses [9]. Anyway, this shows that T15, T27, and T33 treatments are the best for the growth of *G. sylvestre* vine plant cuttings under propagator conditions.

V. CONCLUSION

G. sylvestre plant is a plant with potent medicinal properties, which can treat mainly diabetes and other diseases that humans can suffer from. For this reason, the *G. sylvestre* plant should be grown on a large scale to obtain a qualitative and quantitative harvest. Considering the facts that, plant propagation should be developed, and for that purpose, the present experiment was conducted. The results showed that semi-hardwood and hardwood cuttings types with coir dust potting media are most suitable under the single vegetative propagation method for the growth of *Gymnema* plants in the wet zone of Sri Lanka. By this method, a better survival rate can be maintained. Further investigation is needed to determine whether the proposed factors are safe and economically viable for *G. sylvestre* plants by researching them under another time frame. Moreover, this experiment will be helpful for other research related to *G. sylvestre*.

REFERENCES

[1] M. Syedy and K. S. Nama, "*Gymnema sylvestre* : A miracle fruit for Diabetes cure," *Int J Pure Appl Biosci*, vol. 2, no. 6, pp. 318–325, 2014.

[2] R. M. Chameera Rathnayaka *et al*., "14th-15th 2023 International Research Conference of Sri Lanka Technology Campus Colombo, Sri Lanka. 14 th-15 th," Colombo, Dec. 2023. [Online]. Available: https://www.researchgate.net/publication/378480316

[3] R. Br, V. S. U. P. G. Centre, and A. Pradesh, "Study on Extraction and Purification of Gymnemic Acid from *Gymnema sylvestre*," vol. 9, pp. 305–311, 2019.

[4] I. H. Kontoh, "Effect of growth regulators and soil media on the propagation of *Voacanga africana* stem cuttings," *Agroforestry Systems*, 2015, doi: 10.1007/s10457-015-9870-2.

[5] A. K. Pandey, "Cultivation Technique of an Important Medicinal Plant *Gymnema sylvestre* R. Br. (Gurmar)," *Academic Journal of Plant Sciences*, vol. 5, no. 3, pp. 84–89, 2012, doi: 10.5829/idosi.ajps.2012.5.

[6] A. Rayya, "Effect of Different Collection Times and Some Treatments on Rooting and Chemical Internal Constituents of Bitter Almond Hardwood Cuttings," 2009.

[7] M. Galavi, M. A. Karimian, and S. R. Mousavi, "Effects of Different Auxin (IBA) Concentrations and Planting-Beds on Rooting Grape Cuttings (*Vitis vinifera*)," 2013. [Online]. Available: www.sciencedomain.org

[8] H. Aminah, J. M. Dickb, J. Gracec, and R. I. Smithb, "Effect of indole butyric acid (IBA) on stem cuttings of *Shorea leprosula,"* 1995.

[9] R. M. S. M. B. Rathnayaka, P. S. Warakagoda and S. Subhasinghe, "In vitro callus formation of *Gymnema sylvestre* R. Br.". 2011. International Symposium on Agriculture and Environment, Faculty of Agriculture, University of Ruhuna, Matara, Sri Lanka.

Estimation of Photosynthetically Active Radiation (PAR) Distribution in Coconut-Based Different Intercropping Models

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***Abstract*: Coconut (*Cocos nucifera* L.) is a vital crop in tropical regions, serving as a source of income and sustenance for millions. However, the traditional monocropping system of coconut cultivation often results in underutilizing land and resources. Intercropping, the practice of growing two or more crops in proximity, has emerged as a sustainable solution to maximize land use efficiency and increase overall productivity in coconut plantations. This study examines the distribution of Photosynthetically Active Radiation (PAR) in various coconut-based intercropping systems to improve light use efficiency and overall productivity. This experiment was conducted at the Coconut Research Institute of Sri Lanka, PAR measurements were taken across matured different intercropping models, including coffee, cocoa, starfruit, pepper, and cinnamon, during peak solar hours. Results revealed significant variations in PAR distribution across intercropping categories, with the 'starfruit' category demonstrating the highest light penetration to the understory and 'cinnamon' the least. These findings underscore the importance of crop selection in optimizing light availability and resource utilization in coconut cropping systems. The study highlights opportunities for developing more sustainable, productive intercropping systems by tailoring light distribution to different crop requirements. The study found that PAR distribution followed a diurnal pattern, peaking between 11:30 am and 12:30 pm, and highlights the need to consider environmental factors and plant characteristics to optimize coconut-based agroforestry practices.**

***Keywords:* Intercropping, Light interception, Line quantum sensor, photosynthetically active radiation (PAR)**

I. INTRODUCTION

Light from the sun is essential for growing crops, as it drives photosynthesis and influences how plants develop and produce yields[1]. The characteristics of light - including its type, strength, and how long it shines - determine how effectively plants can capture energy for growth. Photosynthetically Active Radiation (PAR) describes the specific wavelengths of light that plants use for photosynthesis, which fall within the visible spectrum between 400-700 nanometers[2]. Scientists measure PAR using a unit called photosynthetic photon flux density (PPFD), which tells us how many photons hit a given area

over time. Special devices called LI-COR quantum sensors are used to measure PAR levels[3]. PAR measurements are vital for agriculture since they directly affect plant growth, development, and crop quality. However, different plants need different amounts of PAR depending on their species, stage of growth, and environmental conditions. Understanding and measuring PAR is crucial for various applications, from studying plant biology to managing greenhouse lighting[4]. Farmers and researchers rely on PAR meters to monitor and fine-tune lighting conditions. This allows them to provide optimal light levels for specific crops, ultimately helping to maximize both crop yields and quality through precise light management.

Monitoring PAR levels is crucial when introducing companion plants (intercrops) into coconut plantations[2]. Intercropping in coconut farms is a popular strategy to make better use of available land. In traditional coconut farming, trees are spaced 8 meters apart, but this monoculture approach is quite inefficient - using only 22.3% of the land area, 30% of available canopy space, and capturing just 45% of available sunlight[5]. This inefficiency creates opportunities to integrate other crops or livestock into coconut plantations to boost overall farm productivity[6], [7], [8]. Research shows that mature coconut palms have roots extending 1.8 meters out from the trunk, with most root activity in the top 1.2 meters of soil. In mixed planting systems, different crops can share space effectively since their root systems occupy different soil zones[9]. Both irrigated and rain-fed coconut farms can support various companion crops. The key is choosing plants that can thrive without competing too heavily with the coconuts for resources. Crops are planted in the spaces between coconut rows according to specific patterns based on their growth

characteristics. Many different crops can successfully grow alongside coconuts across different climate zones, including, fruits, vegetables, spices, root and tuber crops[5], [10], [11]. The aim of this research was to examine the distribution of PAR in various coconut-based intercropping models to improve light use efficiency and overall productivity.

II. METHODOLOGY

A. location of the Experiment

The research was carried out at the research stations of the Coconut Research Institute of Sri Lanka (CRISL), located in the low country intermediate zone of the North Western province, and the study period extended from March 2024 to September 2024.

B. Data collection

The 8 m x 8 m coconut planting square was divided into equal 1 m x 1 m grid portions. A portable grid corresponding to the layout was prepared to gather data (Fig. 1). There were five intercropping models selected (Table 1). Three coconut squares were randomly chosen for each intercropping category. PAR measurements were taken at 81 points within each square using a line quantum sensor (Fig. 2). The grid was laid under the selected squares, and readings were taken at each intersection point. Data collection occurred primarily between 11:30 am and 12:30 pm, representing the peak solar radiation period. However, additional measurements were taken at regular intervals throughout the day to capture diurnal variations in PAR, from sunrise to sunset.

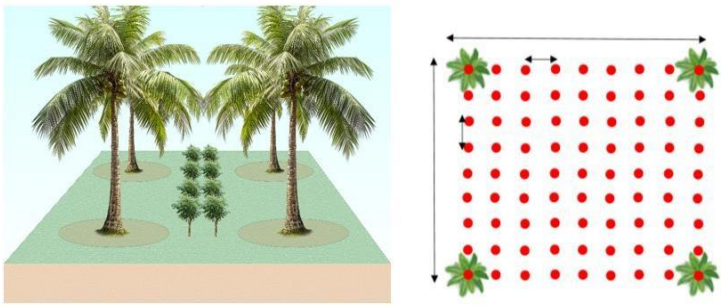

Fig.1: Field layout

Table 1: Selected Intercropping models

Coconut Variety	**Planting System**	**Intercropping Category**
CRIC 60 (Tall x Tall)	Square (26ft x 26ft)	Coffee Cocoa Starfruit Pepper Cinnamon

Fig.2: Line quantum sensor

C. Statistical analysis

R studio (4.1.3) statistical software was used to perform all the statistical analyses.

III. RESULTS

The distribution pattern of PAR exhibited significant daily variations of 6.30 am to 6.30 pm (Fig. 3). Starting with a gradual increase until around 7:30 a.m., the rate of increase slowed due to changing sun angle. After 9:30 a.m., the growth rate accelerated, leading to peak PAR distribution between 11:30 a.m. and 12:30 p.m. Following the peak, PAR levels declined, initially diminishing after 12:30 p.m., followed by a rapid decrease after 1:30 p.m. This diurnal pattern aligns with expected solar radiation patterns and significantly impacts the photosynthesis rates of coconut palms and intercrops throughout the day. This finding aligns with previous research conducted by Udumann et al., 2024 [2], which reported similar distribution pattern.

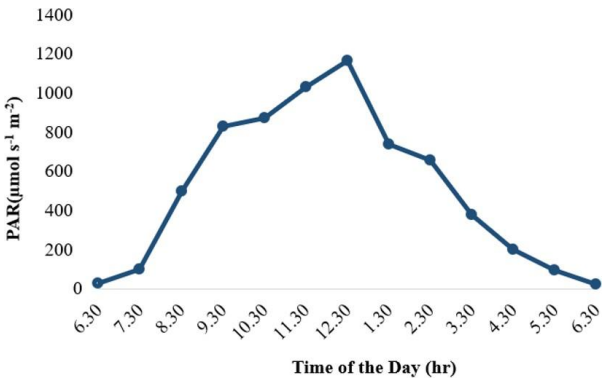

Fig. 3: PAR distribution pattern on the day

Analysis of PAR values across different intercropping categories revealed significant variations (Table 2). Key findings include the 'starfruit' category with the Highest observed PAR value (644.96 µmol m^{-2} s^{-1}). The 'cinnamon' category had the lowest mean PAR value (312.30 µmol m^{-2} s^{-1}). These results suggest that the different intercropping categories significantly influences the PAR distribution in the understory. The 'coffee' category, showing similarly high PAR values, suggests that coffee as an intercrop allows for

significant light penetration to the understory. Conversely, the low PAR values in the 'pepper', ‗cocoa' and 'cinnamon' categories indicate more excellent light interception by these intercrops, potentially due to their growth habits and canopy structures.

Table 2: Descriptive statistic of the PAR

Intercropping model	Minimum	Maximum	Mean
Coconut monocrop (Control)	385	1457	852.12
Coconut+Coffee	205	1281	624.26
Coconut+Cocoa	210	695	329.70
Coconut+Starfruit	200	1323	644.96
Coconut+Pepper	205	664	429.75
Coconut+Cinnamon	210	500	312.30

The heat maps reveal distinct spatial distribution patterns across different substances (Fig. 4). Coconut monocrop exhibits a symmetric pattern with high intensity concentrated in the center that gradually diminishes towards the edges. This finding aligns with previous research conducted by Udumann et al., 2024 [2], which reported similar distribution pattern in 55 years old coconut monocrop. Coffee and pepper share similar grid-like patterns featuring evenly spaced low-intensity dots arranged systematically against a higher-intensity background. Starfruit and cinnamon both display vertical banding patterns, with Starfruit showing alternating intensity stripes and cinnamon having two high-intensity bands on the sides with a lower-intensity central region. Cocoa stands out with its unique cross-shaped or plus-shaped high-intensity clusters against a lower-intensity background.

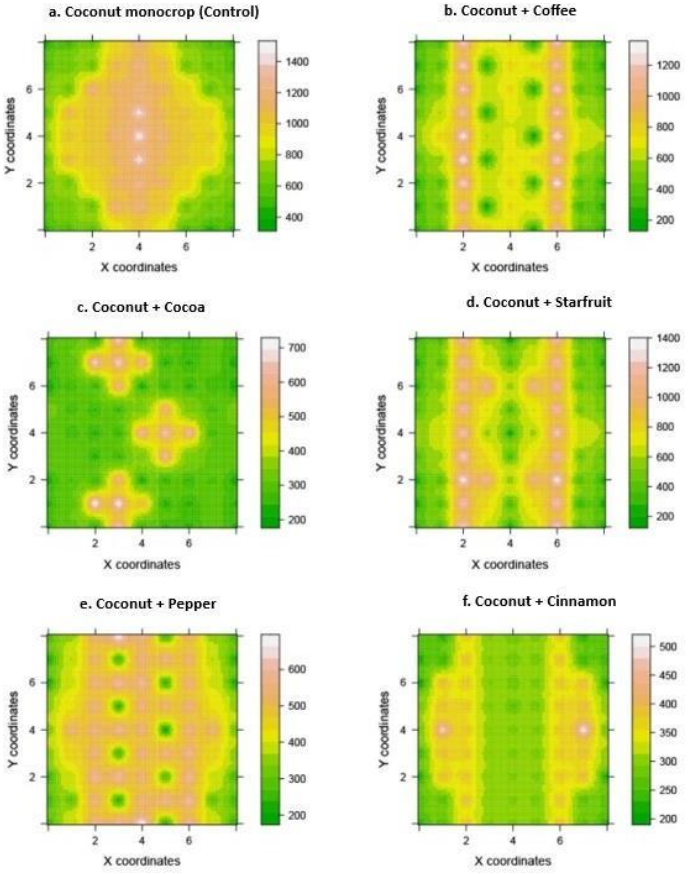

Fig. 4: Spatial distribution of the PAR with different intercropping models; (a) Coconut monocrop, (b) Coconut+ Coffee, (c) Coconut + Cocoa, (d) Coconut + Starfruit, (e) Coconut + Pepper, (f) Coconut + Cinnamon

IV. CONCLUSION

This study's comprehensive analysis of PAR distribution in coconut-based intercropping systems reveals significant variations across different intercrop categories, emphasizing the crucial role of light availability in intercrop selection and management. The findings highlight the potential for optimizing intercrop placement to maximize light use efficiency. These insights can guide farmers and planners in developing more sustainable and productive coconut-based agroforestry systems, ultimately leading to improved resource utilization and increased overall productivity. Future research should focus on long-term studies to examine seasonal variations in PAR distribution patterns, investigate the relationship between PAR distribution and yield of both coconut and intercrops, develop crop-specific PAR thresholds for optimal growth in coconut-based intercropping systems, and explore innovative intercropping designs that maximize light use efficiency while minimizing competition for other resources. In conclusion, this study contributes to a better understanding of PAR dynamics in coconut-based intercropping systems, providing a foundation for more informed and sustainable agroforestry practices.

V. ACKNOWLEDGMENT

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VI. REFERENCES

[1] R. A. Slattery, B. J. Walker, A. P. M. Weber, and D. R. Ort, ―The Impacts of Fluctuating Light on Crop Performance,‖ *Plant Physiol*, vol. 176, no. 2, pp. 990–1003, Feb. 2018, doi: 10.1104/pp.17.01234.

[2] S. S. Udumann et al., ―Optimizing intercropping selection for coconut plantations based on PAR and agro-climatic zones,‖ *Agroforestry Systems*, Apr. 2024, doi: 10.1007/s10457-024-00977-w.

[3] A. Coffin, C. Bonnefoy-Claudet, M. Chassaigne, A. Jansen, and C. Gée, ―PARADe: A low-cost open-source device for photosynthetically active radiation (PAR) measurements,‖ *Smart Agricultural Technology*, vol. 1, p. 100018, Dec. 2021, doi: 10.1016/j.atech.2021.100018.

[4] P. Pinho, K. Jokinen, and L. Halonen, ―Horticultural lighting – present and future challenges,‖ *Lighting Research & Technology*, vol. 44, no. 4, pp. 427–437, Dec. 2012, doi: 10.1177/1477153511424986.

[5] T. Nuwarapaksha, S. Udumann, D. Dissanayaka, D. Dissanayake, and A. J. Atapattu, ―Coconut based multiple cropping systems: An analytical review in Sri Lankan coconut cultivations,‖ *Circular Agricultural Systems*, vol. 2, no. 1, pp. 1–7, 2022, doi: 10.48130/CAS-2022-0008.

[6] T. D. Nuwarapaksha, S. S. Udumann, N. S. Dissanayaka, and A. J. Atapattu, ―Coconut-Based Livestock Farming: A Sustainable Approach to Enhancing Food Security in Sri Lanka.‖ *In Transitioning to Zero Hunger*, Delwendé Innocent Kiba (ed), MDPI Books, 2023, pp.197-213. https://doi.org/10.3390/books978-3-03897-863-3-8

[7] T. D. Nuwarapaksha, U. N. Rajapaksha, J. Ekanayake, S. A. Weerasooriya, and A. J. Atapattu, ―Exploring the Economic Viability of Integrating Jamnapari Goat into Underutilized Pastures under Coconut Cultivations in Coconut Research Institute, Sri Lanka,‖ in

IECAG 2023, Basel Switzerland: MDPI, Oct. 2023, p. 27. doi: 10.3390/IECAG2023-14990.

[8] D. M. N. S. Dissanayaka, S. S. Udumann, and A. J. Atapattu, ―Synergies Between Tree Crops and Ecosystems in Tropical Agroforestry,‖ *in Agroforestry*, Wiley, 2024, pp. 49–87. doi: 10.1002/9781394231164.ch3.

[9] D. M. N. S. Dissanayaka, D. K. R. P. L. Dissanayake, S. S. Udumann, T. D. Nuwarapaksha, and A. J. Atapattu, ―Agroforestry—a key tool in the climate-smart agriculture context: a review on coconut cultivation in Sri Lanka,‖ *Frontiers in Agronomy*, vol. 5, May 2023, doi: 10.3389/fagro.2023.1162750.

[10] S. A. S. T. Raveendra, A. A. A. J. Atapattu, S. H. S. Senarathne, C. S. Ranasinghe, and K. W. L. K. Weerasinghe, ―Evaluation of the Carbon Sequestration Potential of Intercropping Systems Under Coconut in Sri Lanka,‖ *International Journal of Geology, Earth & Environmental Scienc*es, vol. 7, no. 1, pp. 1–7, 2017, [Online]. Available: http://www.cibtech.org/jgee.htm

[11] T. D. Nuwarapaksha, S. S. Udumann, and A. J. Atapattu, ―Fostering Food and Nutritional Security Through Agroforestry Practices,‖ *in Agroforestry*, Wiley, 2024, pp. 285–318. doi: 10.1002/9781394231164.ch10.

Optimization of Multiplication and Initiation Media for *Anthurium* Maine using Growth Regulators

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Abstract- This research optimized the initiation and multiplication media for *Anthurium* Maine using plant growth regulators. The study evaluated the effects of different concentrations of 2, 4-D, and kinetin on callus growth using leaf explants for initiation and established callus for multiplication. It was found, that in initiation, T1 achieves the highest callus weight, especially under dark conditions. For multiplication, T1 produced the best results for callus weight and callus diameter. The study highlights the importance of low Auxin and cytokinin concentrations, along with dark conditions, in optimizing Anthurium tissue culture for large-scale propagation.

Keywords- Anthurium Maine, Tissue Culture, Growth Regulators, Initiation, Multiplication

I. INTRODUCTION

Anthurium, a popular ornamental genus from the Araceae family, is prized for its attractive flowers and exotic foliage, with *Anthurium* Maine being one of the most commercially cultivated varieties of cut flowers globally [1]. Propagation methods for *Anthurium* include seed propagation, traditional vegetative methods, and tissue culture. While seed propagation often results in heterozygous progenies and low germination rates, and vegetative propagation is slow, micropropagation through tissue culture offers a reliable solution for large-scale production of disease-free, genetically uniform plants [2]. Tissue culture has been achieved using various *Anthurium* tissues, such as leaves, petioles, and shoot tips, with the process depending heavily on plant growth regulators (PGRs). The success of this method, particularly in callus formation and shoot proliferation, relies on the concentrations of PGRs like BAP, Kinetin, and 2, 4-D which influence cell division and differentiation. This study aims to optimize 2.4-D and Kinetin concentration in the initiation and multiplication media for *Anthurium* Maine, building on previous research showing that the balance of these PGRs can significantly impact tissue culture outcomes [3].

II. MATERIAL AND METHODOLOGY

The research was conducted at the tissue culture laboratory of the Sri Lanka Technology Campus. The plant materials used for the study included leaf explant for the initiation stage and growth callus for the multiplication stage, both obtained in sterile culture bottles. The leaf explants were prepared for culture, and the growth callus from the previous culture was used to evaluate shoot proliferation under different treatments.

For media preparation, both the initiation and multiplication media were formulated using half-strength MS supplemented with agar and sugar. BAP was maintained at a constant concentration of 2mg/L across all treatments. In the initiation media, 2, 4 D was varied at concentrations of 0.2 mg/L, 0 mg/L,1 mg/L, and 5 mg/L, while kinetin was varied at concentrations of 0.5 mg/L, 0 mg/L, 2.5 mg/L and 4.5 mg/L in the multiplication media. The media were sterilized after preparation to ensure contamination-free conditions throughout the experiment.

The experiment consisted of 10 replicates for the initiation media, with half the replicates kept in darkness and the other half in light for 1.5 months. This light/dark treatment allows for a comparison of growth responses under different conditions. Collect the data in two growth stages, focusing on key parameters such as Callus weight and callus diameters. A completely randomized design (CRD) was used to analyze the experimental data. Statistical analysis was then conducted to evaluate the influence of different concentrations of 2, 4 –D, and kinetin on callus induction and shoot proliferation. The data were analyzed using IBM SPSS Statistics and Microsoft Excel for basic calculations, Tabulations, and graphical presentations.

III. RESULT

The study investigated the effect of four 2, 4 – D, and Kinetin treatments on various parameters of callus weight and callus diameters in initiation and multiplication.

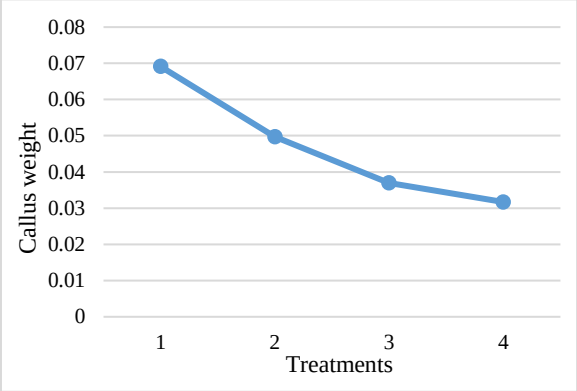
A. Initiation

a. Callus Weight

The effect of varying concentrations of 2, 4-D on callus weight is presented in Table 1 and Graph 1. Treatment 1 exhibited the highest mean callus weight, followed by Treatment 2 with a mean callus weight of 0.04970 ± 0.0008486 g. Treatment 3 resulted in a mean callus weight of 0.03700 ± 0.0003590 g, and Treatment 4 had the lowest mean callus weight.

Treatment	Mean of Callus weight
1	0.06910±0.0017483
2	0.04970 ± 0.0008486
3	0.03700 ± 0.0003590
4	0.03170 ± 0.0002830

Table 1 - Average weight of callus per treatment in the initiation stage.



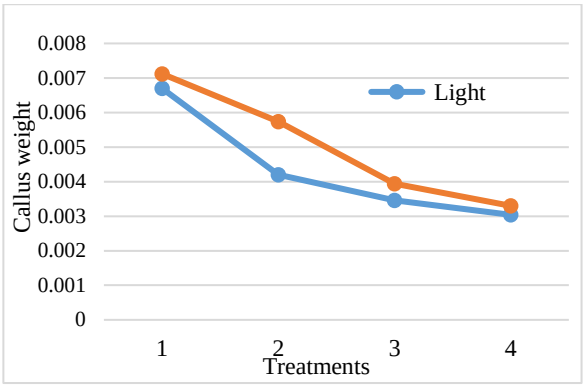
Graph 1 - Effect of the 2, 4 D, BAP concentration for Callus weight

b. Callus Weight In Dark And Light Conditions.

Treatment 1 shows significantly higher callus weight in the dark condition compared to the light condition. Treatment 2 and Treatment 3 also exhibit more growth in the dark condition compared to their light condition values. Treatment 4 follows a similar trend, with higher callus weight in the dark condition than in the light condition. Across all treatments, callus growth is consistently higher in dark conditions compared to light conditions during the initiation phase (Table 2).

Treatment	Callus weight in Light condition	Callus weight in Dark condition
1	0.0067 ± 0.0025884	0..00712 ± 0.000259
2	0.0042 ± 0.00029155	0.00574 ± 0.00023
3	0.00346 ± 0.00032094	0.00394 ± 0.000207
4	0.00304 ± 0.00033615	0.0033 ± 0.000158

Table 2 - Effect of the dark and light conditions for callus



Graph 2: Difference of the callus weight light and dark condition

B. Multiplication

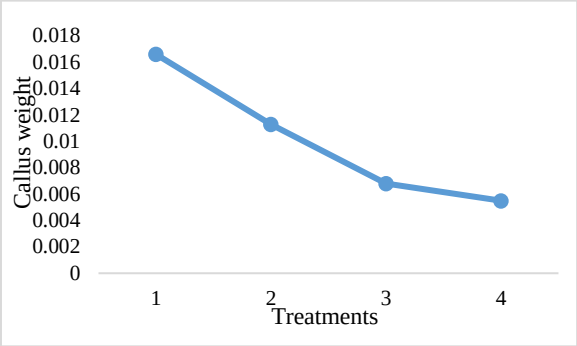
a. Callus Weight

The table presents the average callus weight during the multiplication phase for four different treatments, with the corresponding standard error. Treatment 1 produced the highest callus weight, indicating both substantial growth and relatively low variability. Treatment 2 follows with a slightly lower weight but exhibits higher variability. Treatments 3 and 4 show progressively lower callus weights, indicating reduced callus formation as the treatments change. These results suggest that the effectiveness of callus production varies significantly across treatments, with Treatment 1 being the most effective and Treatment 4 the least (Table 3).

Table 3: Result of callus weight

Treatment	Mean of Weight
1	0.0166 ± 0.00519
2	0.0133 ± 0.002359
3	0.0068 ± 0.004826
4	0.0055 ± 0.00344

Graph 3: Effect of the Different Kinetin, BAP concentrations for callus weight



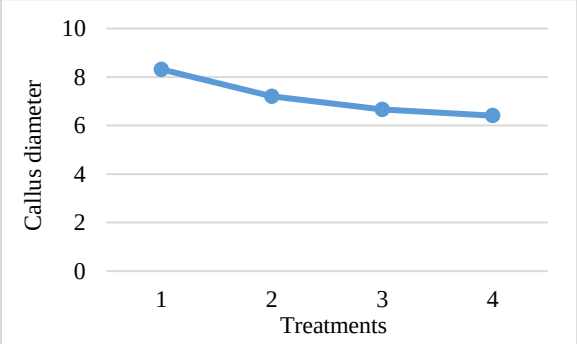
b. Callus Diameter

The table provides an overview of the effects of four different treatments on callus diameter. Treatment 1 demonstrates the highest effectiveness in promoting callus growth, while Treatment 4 shows the least effectiveness, resulting in the smallest callus weight. This trend indicates a consistent decrease in the efficacy of the treatments from Treatment 1 to Treatment 4. The variability in the measurements suggests that further investigation may be necessary to optimize conditions for callus growth across different treatments. Overall, the data highlights the importance of selecting the appropriate treatment to achieve the desired outcomes in callus development (Table 4).

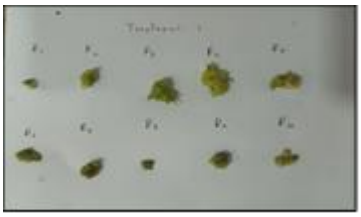
Table 4: Result of callus diameter

Treatment	Mean of diameter
1	8.23 ± 3.478
2	7.39 ± 2.528
3	6.67 ± 1.3888
4	6.41 ± 0.932

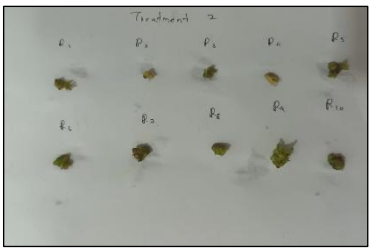
Graph 4: Result of callus diameter in multiplication media



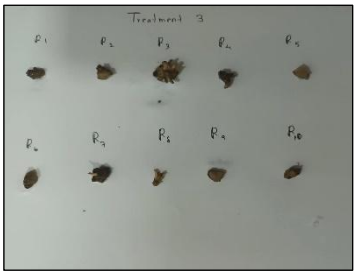
c. Callus Color



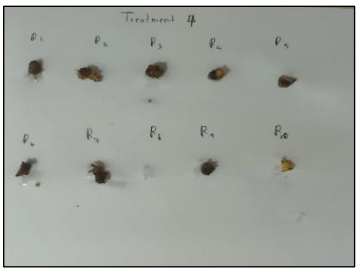
Treatment 1



Treatment 2



Treatment 3



Treatment 4

Treatment 1 produced healthy, green calluses with minimal stress. Treatment 2 showed some browning, indicating moderate stress. Treatment 3 resulted in dark brown calluses with significant deterioration, and Treatment 4 exhibited the most severe necrosis, with even darker browning than Treatment 3.

IV. DISCUSSION

In the initiation stage, the results show that treatment 1 has the highest callus weight, indicating it is the optimal combination for growth. Auxins like 2, 4-D promote cell division, and BAP enhances differentiation. While BAP alone (Treatment 2) supported some callus growth, higher 2, 4-D levels (Treatments 3 and 4) reduced growth, likely due to Auxin toxicity. [4] Callus

weight was notably higher in the dark condition compared to the light condition, indicating that darkness promotes more robust callus formation. This could be attributed to the suppression of photosynthesis-related processes, which may otherwise divert energy away from callus growth under light conditions. Previous studies have similarly reported that darkness often enhances callus induction by reducing light-induced oxidative stress and allowing cells to focus energy on growth and division rather than photosynthetic activity [5].

During the multiplication phase, callus weight was found to be highest in Treatment 1, indicating that this specific treatment combination of growth regulators facilitated better proliferation of callus tissue. Similarly, the callus diameter was also larger in this treatment, aligning with the increased callus weight. These results confirm that manipulating the levels of cytokinins, such as kinetin and BAP, can directly influence both the mass and size of the callus, as supported by the literature. This positive correlation between weight and diameter highlights the effectiveness of Treatment 1 in maximizing callus growth, which is consistent with findings in related plant tissue culture studies that emphasize the role of growth regulators in enhancing cell expansion and proliferation. [6]. Lower kinetin concentrations (T1) supported healthy growth, while higher concentrations (T3 and T4) caused severe stress, leading to necrosis. Moderate browning in T2 suggests early signs of stress, highlighting the need to balance kinetin levels for optimal callus development in *Anthurium* Maine.

Overall, the findings suggest that while darkness is beneficial for callus initiation, specific growth regulator treatments are critical for optimizing both weight and size in the multiplication stage. This highlights the need for fine-tuning hormonal concentrations in tissue culture protocols for optimal growth outcomes, as evidenced by past research.

V. CONCLUSION

This study optimized initiation and multiplication media for *Anthurium* Maine using plant growth regulators. In the initiation stage, (2, 4-D with BAP) treatment 1 yielded the highest callus weight, with better growth in dark conditions. For multiplication, (kinetin with BAP) treatment 1 produced the best results across most parameters, including shoot formation. These findings provide an effective protocol for in vitro propagation, emphasizing the role of growth regulators and environmental conditions in optimizing callus induction and shoot growth.

REFERENCES

[1] M. Jahan and R. K. A. M. G. A. M. R. Islam, "In vitro Clonal Propagation of Anthurium (Anthurium," vol. 19, no. 1, pp. 61-69, 2009.

[2] C. A. A. O. Celik, "Micropropagation of Anthurium andraeanum," vol. 41, no. 3, pp. 1155-1161, 2009.

[3] E. F. H. M. A. &. D. K. G. J. George, "Plant propagation by tissue culture.," 2008.

[4] R. P. S. K. K. M. P. S. Vikash Singh, "Plant growth regulators and their use in plant growth and development," 2021.

[5] J. A. J. V. Staden, "In vitro culture of Anthurium andraeanum".

[6] N. A. B. 2. N.-A. B. H. S. 4. R. Behnam Sedaghati 1, "Effect of type and concentration of growth regulators on the plant," vol. 3, pp. 998-1004, 2012.

Find out a cost-effective organic fertilizer mixture as a solution for leaf yellowing of the *Calathea insignis.*

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Abstract- ***Calathea insignis*** **is a widely cultivated ornamental foliage plant with aesthetic value and significant demand in the export market. However, the predominant issue at present is the yellowing of leaves in this foliage. This study compares the performance of organic fertilizers such as Fish tonic, Fruit tonic, and Sakkara with traditional chemical fertilizers such as Yaramila, Albert solution, and Young Palm Mixture. Leaf length and color were measured as key plant growth parameters to determine the efficiency of treatments. The results show that organic fertilizer (Sakkara and Fish tonic), considerably reduces leaf yellowing by allowing optimum leaf development against the control group, which had 49.04 cm. Bud formation and leaf pigmentation also increased under the organic treatments indicating improvement in plant health Statistical analysis confirmed that organic fertilizers were preferable for reducing nutrient deficiencies and improving the aesthetic appeal of plants. Findings reveal that organic treatments are cost-effective and more environmentally sustainable than chemical fertilizers to be used in the floriculture industry. This contributes to the ongoing discussion on sustainable agricultural practices by offering the benefits of organic fertilization for improving the quality of export of** ***Calathea insignis*****.**

Keywords – Calathea insignis, organic fertilizers, chemical fertilizers, leaf yellowing, leaf length, leaf color, bud formation, nutrient deficiencies, cost-effectiveness

I. INTRODUCTION

Foliage plants are a category of plants that are cultivated for the visual appeal of the leaves instead of the flowers of the plants [1]. These plants have a wide variety of shapes of leaves, sizes, colors, and patterns [2]. Most people select foliage plants for gardening, landscaping, and interior decorations. The famous foliage plants are ornamental grasses, *Calathea*, Snake plants, etc. [3]. These plants are not only visually pleasing but are also appreciated for their ability to thrive with relatively low maintenance, making them accessible to both seasoned gardeners and those new to plant care [1].

Calathea plants belong to the *Marantaceae* family, native to South America, and distributed in tropical countries such as Asia and Africa. *Calathea insignis* and *Calathea makoyana* are widely used foliage plants for the decorations on interiors and exteriors from 300 species. *Calathea insignis* plant commonly known as the “Rattlesnake plant” has narrow leaves, tapering, and many wavy margins [1]. These plants are suitable for indoor and shaded outdoor areas and export purposes. This is an expensive plant and has demand. *Calathea insignis* leaves turn yellow for many reasons such as lighting issues, overwatering, disease, and nutrient deficiency [4]. Lighting issues can be controlled by applying an 80% shade net for the net house, as the *Calathea insignis* is sensitive to changes in water conditions have to maintain consistent soil moisture without allowing the plant to sit in

water, diseases can be controlled by applying fungicides and as the chemical fertilizers are applied to this plant [5], sometimes yellow color can be seen in leaves [6]. The other reasons can be controlled but nutrient deficiency can be controlled by changing the fertilizers. Due to the yellowing of leaves, the exporting demand for the plant decreases and also the leave length should be about 60 cm [7].

The leaves of *Calathea insignis* turn yellow, which changes the texture of the plant, reduces the quality of the plant, and causes the beauty of the gardens also export companies have to face many problems as the demand decreases. So, to mitigate those problems organic fertilizers (Fruit tonic, Fish tonic, and Sakkara) are made and tested. This research is done to check whether those fertilizers can prevent the yellowing of the leaves.

II. MATERIALS AND METHODS

A. Study Location

The research was conducted in a controlled environment at the Huejay Floriculture farm in Mahawatta, Divulapitiya. The study site was carefully selected to ensure optimal growing conditions for Calathea insignis and to allow for accurate

monitoring of environmental factors such as temperature, humidity, and light exposure. These controlled conditions helped minimize external variables that could influence plant growth and leaf coloration, ensuring that the effects observed were primarily due to the different fertilizers being tested.

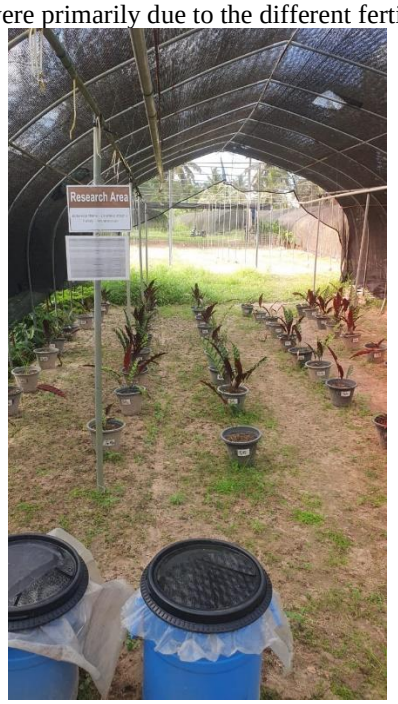

Fig 1. Research location

Crops and conditions of growing area

This study was conducted in a net house at the Huejay Floriculture farm, where the middle age of 45 *Calathea insignis* plants with yellowing leaves were grown. The net house provided a semi-controlled environment, allowing for natural light and air circulation while minimizing external disturbances such as pests or extreme weather conditions.

B. Preparation of organic fertilizers for the plants

Fish waste, water, and jaggery were used to prepare the Fish tonic. Fish waste was collected and ground into small pieces, which were then placed into a plastic bucket and Jaggery (1 kg) was broken into small pieces and added to it. The mixture was stirred thoroughly, water was added, and the bucket was sealed with a lid to allow fermentation. After 10 to 14 days, the lid was opened, and additional jaggery or sugar was added to the mixture. The contents were mixed well and left to ferment for another 14 days. After a total of 21 days, the lid was opened, and the mixture emitted a smell resembling that of a ripe wood apple, indicating the tonic was ready for use. The mixture was filtered and stored in dark bottles to protect it from sunlight. For application, 20 ml of fish tonic was mixed with 1 liter of water and sprayed on the plants at 7-day intervals, starting on the 10th day of plant age.

Ripe banana, papaya, pumpkin, jaggery, egg, and water were used to prepare the Fruit tonic. Bananas, papayas, and pumpkins were peeled and chopped into small pieces, and then placed in a plastic container. Sugar was added to the chopped fruits, and the mixture was stirred thoroughly. One egg and 10 liters of water were added to the container, and the ingredients were mixed well. The container was then sealed with a lid and left to ferment for 21 days. After fermentation, the mixture was strained, and 1 liter of the tonic was diluted with 20 liters of water. The diluted tonic was sprayed on the soil and foliage in the evening. This fertilizer was found to promote crop growth and also acted as a natural pest control agent.

Sakkara was prepared by dissolving 5 kg of jaggery in a 20-liter barrel of water and left to ferment for use.

C. Applying treatments for the plant

The treatments for the plants were applied according to the following table

TABLE I. APPLYING TREATMENTS FOR THE PLANTS

Treatment no	Treatment	Amount
T_0	Control treatment (Albert solution 4 g + Yaramila 5 g)	
T_1	YPM	5 g
T_2	Fish tonic	250 ml to soil
T_3	Fruit Tonic	250 ml to soil
T_4	Sakkara	250 ml to soil 20 ml to 1l of water to spray
T_5	Fish tonic + Fruit tonic+ Sakkara	250 ml to soil 20 ml to 1l of water to spray
T_6	Fish tonic + Fruit tonic	1:1 (250 ml to soil) 20 ml to 1 L of water to spray
T_7	Fish tonic + Sakkara	1:1 (250 ml to soil)
T_8	Sakkara and Fish tonic	1:1 (250 ml to soil)

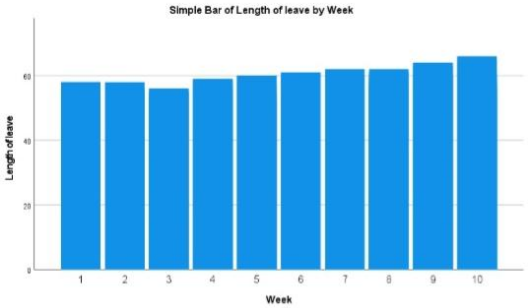

Fig 2. Length of leaves by week

The fertilizers were applied according to the specified dosages and schedules, ensuring consistent care across all groups. The organic fertilizers were prepared using fermentation processes as described earlier, while the chemical fertilizers were used according to standard agricultural practices.

D. Monitoring and Data collection

Over the study period, the plants were monitored closely, with regular observations focusing on the reversal of yellowing in the leaves. Changes in leaf color, from yellow to green, were recorded at regular intervals. Additional growth metrics, such as leaf length and overall plant health, were also measured to evaluate the broader effects of each fertilizer.

E. Cost-effectiveness analysis

After the treatment period, the performance of each fertilizer was analyzed. The organic fertilizers, particularly Fish Tonic, Fruit Tonic, and Sakkara were evaluated not only for their efficacy in restoring green leaf color but also for their cost-effectiveness in comparison to chemical alternatives. Factors such as the price of raw materials, preparation time, and the required application frequency were considered in determining the most economical and effective solution.

III. RESULTS AND DISCUSSION

The study evaluated the effect of different organic and chemical fertilizers on leaf yellowing, leaf length, bud growth, and leaf color in *Calathea insignis*. The descriptive statistics reveal notable differences in plant responses based on the treatment applied.

A. Length of Leaves

Across the treatments, the average leaf length varied significantly. Treatment 7 (Sakkara and Fish tonic) showed the highest mean leaf length at 56.44 cm, while Treatment 1 (control) had the lowest mean at 49.04 cm. The overall mean length of leaves across all treatments was 51.99 cm, with a standard deviation of 4.23. The ANOVA results confirmed significant differences between treatments (`F = 17.304, p < 0.001`), indicating that fertilizers had a considerable impact on leaf length. Tukey's post-hoc tests further revealed that the leaf length increased significantly after Week 7.

B. Color of Leaves

Leaf color was evaluated using multiple methods to ensure accuracy and reliability. A Munsell Color Chart, specifically designed for plant leaves, was employed to visually assess the color and categorize each leaf into different shades of green and yellow. This provided a qualitative comparison across all treatment groups.

Leaves treated with organic fertilizers, particularly Sakkara and Fish tonic, maintained a deeper green shade, scoring between 5GY to 7.5GY on the Munsell Color Chart, indicating minimal yellowing.

The color of leaves remained constant during the initial five weeks, averaging a score of 5.00. However, from Week 6 onwards, there was a steady increase in leaf color, reaching a peak of 7.64 in Week 10. Treatment 7 (Sakkara and Fish tonic) had the highest color score (6.64), while the control treatment remained unchanged. The ANOVA results showed that both the week and the type of treatment had a significant effect on leaf color (`F = 224.046, p < 0.001`).

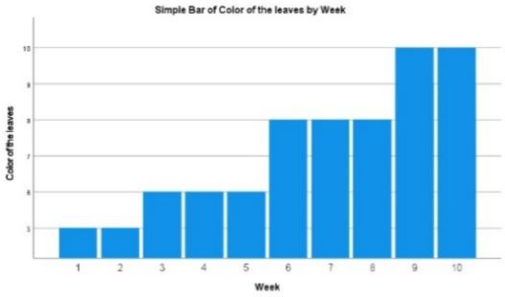

Fig 3. Color of leaves by week

The findings suggest that organic fertilizers, particularly Sakkara, have a significant positive effect on the growth and health of *Calathea insignis*. Various organic fertilizer sources as combined solutions can increase the outputs (yield) compared to the standard fertilizing procedures [8, 9].

The plants treated with Sakkara exhibited the longest leaves, most buds, and the deepest leaf color, indicating that this organic treatment is effective in promoting both aesthetic and functional plant characteristics. Organic fertilizer solution with the combination of pineapple peel, fish, and shrimp wastes for hydroponic cultivation has resulted in the highest plant growth rate compared to commercial chemical fertilizers [10]. The yellowing of leaves, a primary concern, was notably reduced under the organic treatments, particularly from Week 6 onward. This may be due to the consistent supply of essential nutrients that organic fertilizers provide, which are important for chlorophyll production and overall plant health. The significant difference in leaf color improvement suggests that organic treatments might be more effective in addressing nutrient deficiencies that lead to yellowing.

IV. CONCLUSION

This research demonstrates that organic fertilizers, particularly Sakkara and fish tonic, are highly effective in promoting growth and improving the health of *Calathea insignis*. The results showed that plants treated with Sakkara exhibited the longest leaves, the highest number of buds, and the most vibrant leaf color compared to those treated with chemical fertilizers or left untreated. These findings support the hypothesis that organic fertilizers can significantly reduce leaf yellowing, enhance leaf length, and improve overall plant aesthetics.

The study highlights the benefits of using organic fertilizers over chemical alternatives, not only in terms of growth

performance but also in addressing nutrient deficiencies that lead to leaf yellowing. Organic treatments provide a consistent supply of essential nutrients, improving chlorophyll production and enhancing plant health without the environmental or long-term risks associated with chemical fertilizers.

The use of organic fertilizers such as Sakkara and Fish tonic offers a cost-effective and sustainable solution for growers seeking to maintain the quality and marketability of *Calathea insignis*. This research suggests that organic fertilizers should be considered a viable alternative to conventional chemical fertilizers, particularly in environments where plant aesthetics and health are critical.

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REFERENCES

[1] Assefa, S. (2019). The principal role of organic fertilizer on soil properties and agricultural productivity: A review. Agric Res Technol, 22(2). https://doi.org/10.19080/artoaj.2019.22.556192

[2] Zhang, L., Sun, X., Tian, Y., & Gong, X. (2013). Composted green waste as a substitute for peat in growth media: Effects on growth and utrition of Calathea insignis, PLoS On 8(10). https://doi.org/10.1371/journal.pone.0078121

[3] Nguyen, H. C., Lin, K. H., Hsiung, T. C., Huang, M. Y., Yang, C. M., Weng, J. H., & Chang, K. C. (2018). Biochemical and physiological characteristics of photosynthesis in plants of two Calathea species. International Journal of Molecular Sciences, 19(3), 704.

[4] Conover, C. A., & Poole, R. T. (1982). Influence of nitrogen source on growth and tissue nutrient content of three foliage plants. proceedings of the Florida State Horticultural Society, 95, 151-152

[5] Faust, J. E., & Dole, J. M. (2021). Cut foliages. In Cut Flowers and foliages (p. 150).

[6] Chen. (2002). Development of new foliage plant cultivars. ResearchGate Retrieved from https://www.researchgate.net/publication/237329438

[7] Eapen, S. M. (2003). Evaluation of tropical plant species for use as cut foliage (Doctoral dissertation, Department Of Pomology And Floriculture, College Of Horticulture, Vellanikkara).

[8] Wijesundara, W. M. T. I., M. M. J. Harshana, M. D. D. W. Jayathilaka, M. A. U. P. Munasinghe, H. K. S. P. Bandara, H. M. V. T. Jayamal, I. G. S. H. Bandara, R. M. S. H. Rathnayake. H. G. H. Madusanka, M. R. C. S. B. Alahakoon, M. A. P. Madushani, B. K. B. Kavinda, W. K. N. H. Wijesekara, K. A. C. G. Kodithuwakku, B. M. C. B. Balasooriya, J. T. L. Madushanka, D. D. N. Vibodhani, R. M. P. I. Rajapaksha, and R. M. S. M. B. Rathnayaka. (2023). Enhancing yield of Tomato (*Lycopersicon esculentum* Mill.) in Sri Lanka through organic fertilizer solutions. 3rd International Research Conference of Sri Lanka Technological Campus, Colombo, Sri Lanka.

[9] Rajapaksha, R. M. P. I., W. M. T. I. Wijesundara, M. M. J. Harshana, M. D. D. W. Jayathilaka, M. A. U. P. Munasinghe, H. K. S. P. Bandara, H. M. V. T. Jayamal, I. G. S. H. Bandara, R. M. S. H. Rathnayake. H. G. H. Madusanka, M. R. C. S. B. Alahakoon, M. A. P. Madushani, B. K. B. Kavinda, W. K. N. H. Wijesekara, K. A. C. G. Kodithuwakku, B. M. C. B. Balasooriya, J. T. L. Madushanka, D. D. N. Vibodhani, and R. M. S. M. B. Rathnayaka. (2024). Effect of organic fertilizer solutions on the growth and yield of Tomato (*Lycopersicon esculentum* Mill.). Organic Agriculture, PREPRINT (Version 1) available at Research Square [https://doi.org/10.21203/rs.3.rs-3870411/v1].

[10] Athukorala, A.H.D., C.S. De Silva, R. M. S. M. B. Rathnayaka, and S. De Silva, (2024). *Vrikshayurveda* concept of *Kunapa jala* as a cost-effective organic fertilizer solution for Hydroponics to grow Lettuce *(Grand Rapido), International Research Symposium on Traditional Medicine (AyurEx Colombo).*

Identifying High-Quality Cost Effective Growing Media to Enhance Mushroom Production in Sri Lanka(American Oyster mushroom*(Pleurotus ostreatus)*

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Abstract - The Research, titled *Identifying High-Quality, Cost-Effective Growing Media to Enhance Mushroom Production in Sri Lanka,* addresses the need to identify sustainable and affordable substrates for the cultivation of American oyster mushrooms (*Pleurotus ostreatus*). The research responds to the growing demand for mushrooms in Sri Lanka and the challenges posed by the limited availability of traditional growing media such as rubber sawdust. The study evaluates 11 different media, including combinations of rubber sawdust with materials like mango sawdust, paddy straw, and banana leaves. The methodology involved a randomized complete block design with 20 replicates per treatment to ensure the accuracy of results. Key variables measured included mycelial colonization, yield, and biological efficiency, with sterilization and controlled environmental conditions maintained throughout. The study concluded that rubber sawdust, when combined with mango and lunumidella sawdust, significantly enhanced yield and mycelial growth. Although paddy straw and banana leaves offered cost-effective alternatives, they required further optimization to improve productivity. Ultimately, the findings suggest these locally available, nutrient-rich substrates can lower production costs and enhance the sustainability of mushroom farming in Sri Lanka.

Keywords— American Oyster, Saw dust, Harvest, Cost-effective, Yield.

I. INTRODUCTION

Mushroom cultivation, especially of the American Oyster mushroom (*Pleurotus ostreatus*), has gained global attention due to its nutritional benefits, economic potential, and adaptability to various substrates. As one of the most cultivated species, *Pleurotus ostreatus* thrives on a wide range of lignocellulosic materials, making it ideal for sustainable agricultural practices. In Sri Lanka, the increasing demand for mushrooms underscores the importance of selecting cost-effective, high-quality growing media to optimize production and profitability.

Growing media, also known as substrates, play a critical role in mushroom cultivation by providing structural support and essential nutrients for mycelial growth. Traditional substrates, such as rubber sawdust, are commonly used but face limitations due to increasing costs and scarcity. Therefore, the identification of alternative substrates is essential for sustainable and profitable mushroom farming. This study aims to explore various locally available organic waste products, such as mango sawdust, paddy straw, and dry banana leaves, to find effective substitutes for rubber sawdust. By identifying sustainable, nutrient-rich growing media, this research not only contributes to enhancing mushroom production but also promotes the reuse of agricultural waste, benefiting both small-scale and commercial growers in Sri Lanka.

II. MATERIALS AND METHOD

A. *Preparation Of Basic Ingredients And Study Location*

For testing, the collected raw materials were adjusted to the required condition. As treatments Rubber*(Hevea brasiliensis)* sawdust, Mango(*Mangifera indica*) sawdust, Lunumidella(*Melia azedarach*) sawdust, *Albizia*(*Albizia Julibrissin*) sawdust, paddy(*Oryza*) straw (cut into 3-5 cm size), and dried banana leaves(*Lagerstroemia speciosa*) (cut into 1-2 cm size) were obtained separately from the respective stations, and all samples were dried under direct sunlight for 3-4 days until the water was removed. The objective of the drying was to control the blisters and diseases that can occur by keeping water in the media.

Additional nutrients, including Samaposha, Magnesium sulfate, Gypsum, Rice powder, and Dolomite were used according to the recommendation of the agricultural department [1], [2], [3], [4] (TABLE I). Before mixing the rice powder into the medium, use a rice powder sieve to remove large pieces and debris.

TABLE I: DEPARTMENT RECOMMENDATION

20Kg of main material	
Nutrients	**Quantity**
Rice Powder	2Kg
Cao/Dolamite	400g
Soya flour/Samaposha/Chickpea flour	200g
MaSo4	40g

B. *Experimental Design*

The study was structured using a Randomized Complete Block Design (RCBD) with 20 replicates per treatment to ensure statistical accuracy. Eleven treatments were formulated using combinations of sawdust and organic materials [5].

C. *Media preparation and filing into media bags*

The additional nutrients recommended by the Department of Agriculture are prepared separately for treatment 11 by using the main media materials in the proportions mentioned in TABLE II. Transparent polythene bags (14 inches long and 7 inches wide) were filled using the above-mentioned media (TABLE II).

TABLE II: TREATMENTS COMBINATION

Treatments Number	Potting Medias
T1(Control)	Rubber Sawdust (Only)
T2	Mango Sawdust (Only)
T3	Mango Sawdust + Rubber Sawdust (1:1)
T4	Albizia Sawdust (Only)
T5	Albizia Sawdust +Rubber Sawdust (1:1)
T6	Paddy Straw (Only)
T7	Paddy Straw + Rubber Sawdust (1:1)
T8	Lunumidella Sawdust (Only)
T9	Lunumidella Sawdust + Rubber Sawdust (1:1)
T10	Dry banana leaves(Only)
T11	Dry banana leaves + Rubber Sawdust (1:1)

Cultivation bags were filled up to 10 inches in height, and each bag included a piece of 3/4 PVC pipe for the inoculation. A piece of stuffing was placed inside the ring, covered with a paper sheet (6 cm by 6 cm), and measured the final weight before sterilization. (TABLE III)

TABLE III: WEIGHT OF THE BAGS

Treatments Number	Weight Of the Bags (g)
T1(Control)	1005 - 1190
T2	1009 - 1205
T3	1100 - 1202
T4	1100 - 1250
T5	1000 - 1100
T6	450 - 500
T7	670 - 690
T8	990 - 1150
T9	1125 - 1260
T10	390 - 450
T11	590 - 680

D. *Crop Bag Sterilization and introduction of spores into cultivation bags*

Filled polybags were sterilized using a 50-liter iron barrel. After sterilization, the crop bags were left in a chamber to rest for 24 hours before further use [6].

Healthy mushroom seeds of the advanced American oyster (*Pleuritus ostreatus*) type were used for inoculation and confirmed that seeds had a minimum purity of 100%, with a date of manufacture of May 12, 2024, and an expiry date of July 5, 2024. The seed spread percentage was 95%.

The seed introduction process was done at a cleaned workspace, with a simple sterilization procedure which is normally used when inoculation mushrooms mentioned below. All the materials and equipment were sterilized and take all precautions to avoid contamination from other spores.

Three spoonfuls of seeds (about 6 g) were introduced into each cultivation bag after removing the paper and stuffing. The bags were then resealed with a rubber band. This process was repeated for all replicates, and the bags were placed upside down in a dark room, away from direct sunlight until mycelium fully grew.

E. Harvesting

Complete fungal network growth in all treatments was observed for 33 days, prompting the removal of cultivation bag lids to facilitate mushroom growth. Tools used for this process were sterilized, and the crop house was thoroughly cleaned to prevent pathogen entry. The crop bags were placed horizontally, and maintenance involved keeping the temperature between 28 °C and 30 °C, with humidity at 65 % to 85 %. The floor was wetted to maintain humidity, and insect-repellent traps were used to control pests. Daily watering ensured the crop bags were adequately moistened. Mushrooms began to emerge from treatments T5, T6, T8, and T11 within four days, reaching the harvesting stage in two days. Treatments T4, T7, and T9 showed flowering five days after bag opening and were harvested three days later. T1 and T2 flowers emerged and were ready for harvest three days post-emergence, while T3 and T10 followed, with flowering occurring on July 14 and 16, respectively, and harvesting completed two days later.

III. MONITORING AND DATA COLLECTION

The study was conducted over four months to obtain data on mushroom cultivation, the first readings were taken from mycelium growth. Total wet weight of the harvest from one packet, the weight of one matured mushroom, final dry weight, mushroom width, and length, No of flowers per bunch, and Number of days to reach full bloom(Days).

A. Data Analysis

To determine the highest quality yield, mushroom network growth (cm) after harvesting, full mushroom flowers wet weight (g), One flower weight (g), Flower width (cm), flower length (cm), No of flowers (No), Day to full bloom (days), Dry weight (cm),.Statistical analysis was performed using the ANOVA, version. This study used a one-factor factorial design with 20 replicates per treatment.

IV. RESULTS

A. Mycelium growth parameter(cm)

Mycelium growth was completed within one month (33 Days) and no significant difference was observed in the mycelium growth. However, the growth rate in T9 was found to be relatively low compared to other treatments (FIGURE I).

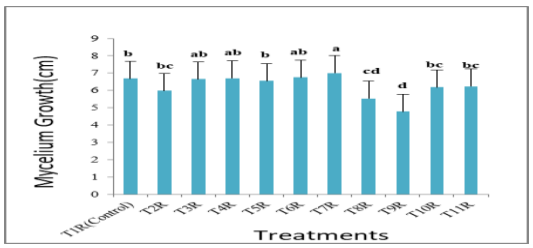


FIGURE I: RESULT OF MYCELIUM GROWTH PARAMETER

B. Yield Parameters

a. Full mushroom flowers weight(g)

The Control treatment (T1) had the highest total flower weight, approximately 63g.T9 and T10 produced flowers with significantly lower weight. (FIGURE II)

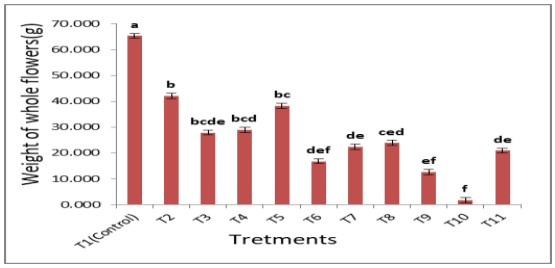


FIGURE II: RESULT OF WHOLE FLOWER WEIGHT

b. No of flowers(No)

The number of flowers in a mushroom cluster was considered here and according to the results, the highest number of flowers was obtained by T3 treatment. The T8 treatment had the highest flowering rate and produced a higher number of flowers compared to the control treatment. Other treatments show some similarity to the control trial. The lowest number of flowers was obtained from T10 (FIGURE III).

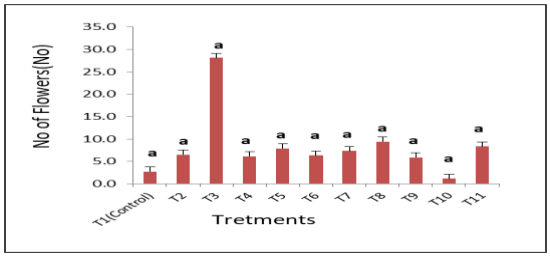


FIGURE III: RESULT OF NO OF FLOWERS

c. Weight of flower(g)

Mushroom weights were similar in weight to T4 and T3 in the control treatment. Other tests showed significant differences (FIGURE IV).

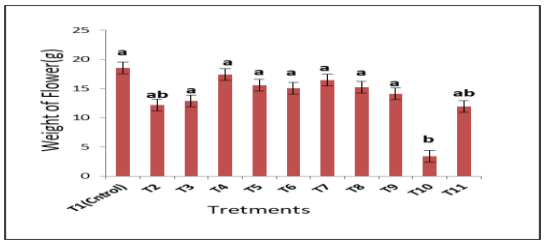


FIGURE IV: RESULT OF FLOWER WEIGHT

d. Flower width (cm)

Here the width of the mushroom flower T3 treatment is higher than the control experiment.T2, T6, and T7, treatments show a slight decrease, but the three are similar, the T10 treatment shows the lowest fruit of a flower.

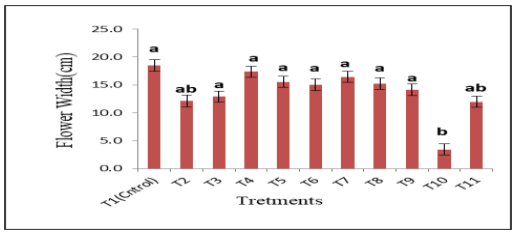


FIGURE V: RESULT OF FLOWER WIDTH

e. Flower length(cm)

Based on the results, the flower length in the control group is the longest, while other treatments show a slight decrease in length. The shortest flower length is observed in treatment T9. (FIGURE VI)

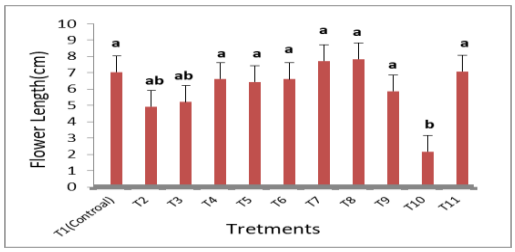
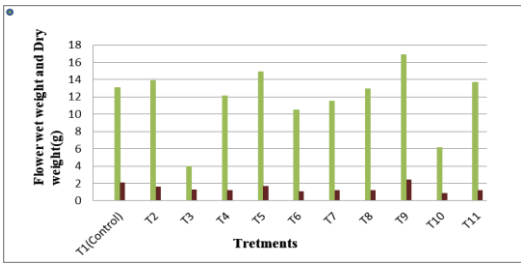


FIGURE VI: RESULT OF FLOWER LENGTH

C. Wet and Dry weight of flower(g)

The wet and dry weight analysis of mushroom flowers revealed that the control group (T1) had the highest flower weight, while T9 and T10 showed the lowest. Although the control produced heavier mushrooms, alternative, cost-effective treatments led to lower weights, indicating the potential for media optimization (GRAPH VII).



FIGUREVII: RESULT OF FLOWER WET WEIGHT AND DRY WEIGHT

V. DISCUSSION

The study's findings align with previous research on mushroom cultivation, indicating that media composition plays a crucial role in optimizing yield and growth efficiency. The combination of Rubber sawdust with Mango and Lunumidella sawdust significantly enhanced mycelial colonization and yield, corroborating earlier work highlighting the importance of nutrient-rich substrates [1], [2]. However, treatments involving paddy straw and banana leaves showed lower yields, consistent with findings that media lacking sufficient nutrients lead to diminished growth [3]. Using local, organic waste materials (like mango sawdust and paddy straw) helps recycle agricultural waste and lessens the need for rubber sawdust, which is getting harder to find. This approach supports sustainable farming and is better for the environment. These results suggest that while cost-effective, some alternative substrates may require nutrient supplementation [4], [5] to match the productivity of more traditional media [6]. Moreover, in addition to the growing media, alternative supplements (Chickpea, green gram flour) to the common mixture that was used by farmers showed the fastest mycelia growth [7].

VI. CONCLUSION

In conclusion, this research identified several cost-effective, locally available substrates that can significantly enhance mushroom production in Sri Lanka, particularly for *Pleurotus ostreatus* (American oyster mushroom). Among the tested media, combinations of rubber sawdust with other organic materials, such as mango and lunumidella sawdust, demonstrated superior performance in terms of mycelial growth, yield, and biological efficiency. Paddy straw and banana leaves also showed promise as

affordable and effective alternatives. The findings suggest that incorporating these readily available substrates into mushroom cultivation could reduce dependency on rubber sawdust, lower production costs, and provide a sustainable solution for mushroom farmers in Sri Lanka. These outcomes have the potential to improve the profitability and scalability of mushroom farming, contributing to both food security and sustainable agricultural practices in the region.

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REFERENCES

[1]. Sianturi, M., & Sabrina, T. (2021, June). Effect of giving triple super phosphate and dolomite fertilizer on mushroom media (baglog) on the production of white oyster mushroom (Pleurotus ostreatus). In IOP Conference Series: Earth and Environmental Science (Vol. 782, No. 4, p. 042044). IOP Publishing.

[2]. Zieba, P., Sekara, A., Bernas, E., Krakowska, A., Sułkowska-Ziaja, K., Kunicki, E.,& Muszynska, B. (2021). Supplementation with magnesium salts—a strategy to increase nutraceutical value of Pleurotus djamor fruiting bodies. Molecules, 26(11), 3273.

[3]. Tang, E. N., Ngome, F. A., Ndindengc, S. A., Bigoga, J. D., Suh, C., & Moreira, J. (2019). Rice residues can be converted to functional health nutrients through mushroom (Pleurotus ostreatus Jacq. ex Fr.) Kummer production. Agriculture and Natural Resources, 53(5), 506-514.

[4]. Gerrits, J. P. G. (1977). The significance of gypsum applied to mushroom compost, in particular in relation to the ammonia content. Netherlands Journal of Agricultural Science, 25(4), 288-302.

[5]. Arisha, M. H. M. E., & El-Hady, M. (2010). Optimum medium for oyster mushroom production. Unpublished Thesis for MS Agriculture). Zagazig University. Retrieved from http://www. academia. edu.

[6]. Gowda, N. N., & Manvi, D. R. O. N. A. C. H. A. R. I. (2020, September). Agriculture crop residues disinfection methods and their effects on mushroom growth. In Proc Indian Natl Sci Acad (Vol. 86, pp. 1177-1190).

[7]. Sirisinghe, W. G. Y. S., W. R. C. M. Waidyarathna, W. H. P. K. Priyankara, W. G. R. P. Ravihara, W. M. Dhilani, G. K. S. S. Gangodawila, R. M. P. I. Rajapaksha, D. D. N. Vibodhani, R. M. S. M. B. Rathnayaka. (2023). Suitability of different supplements for the growth and yield of oyster mushroom cultivation. 3rd International Research Conference of Sri Lanka Technological Campus, Colombo, Sri Lanka

Sustainable agriculture (Environment)

Assessing Tree Diversity and Vegetation Composition in Wet Lowland Rice Associated Eco Units in Pelawattha, Sri Lanka: A Comparative Study of Riceland Associated Homegardens, Kalavita, and Owita Systems

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***Abstract*—Wet lowland Riceland-associated eco units in Sri Lanka represent sustainable agricultural landscapes that significantly benefit ecosystem restoration by establishing high biodiversity and biomass. This study aimed to analyze the vegetation composition, structure, and tree diversity of dominant paddy land associated agroecosystems in Pelawatta (WL1), Sri Lanka, focusing on Riceland-associated homegardens, *Kalavita*, and *Owita* systems. Ten samples were randomly selected from each eco unit. Plant species were identified, recorded, and classified based on uses, origin, and growth form, with tree species measured for diameter at breast height (DBH). The Shannon-Wiener Index was used to estimate tree diversity. A total of 187 plant species, including 23 tree species (260 trees), were identified in homegardens; 74 species, including 12 tree species (146 trees), in the *Kalavita* system; and 97 species, including 15 tree species (214 trees), in the *Owita* system. The Shannon-Wiener index values ranged from 1.77 to 2.32 (mean 2.00) for homegardens, 0.30 to 1.54 (mean 1.16) for *Kalavita*, and 1.12 to 1.67 (mean 1.44) for *Owita*. Results indicated that Riceland-associated homegardens exhibit the highest tree diversity. In conclusion, wet lowland Riceland-associated eco units in Sri Lanka harbor a diverse range of plant species, including exotic, native, and endemic varieties, contributing to rich agrobiodiversity. This highlights the ecological and agricultural value of these traditional farming systems in promoting biodiversity and ecosystem resilience.**

Keywords*—Agrobiodiversity, Eco units, Kalavita, Owita, Riceland-associated homegardens

I. INTRODUCTION

Rice, regarded as the cornerstone of sustenance in the developing world, represents a critical cereal crop, serving as a dietary staple in no fewer than 33 nations. Its significance transcends basic nutrition, becoming deeply entwined with cultural, historical, and ecological dimensions. Within the complex framework of global rice cultivation, Sri Lanka stands out as a notable participant, with a history extending over 2500 years, traced back to the Indo-Aryan migrants [1]. The evolution of rice cultivation in Sri Lanka reflects adaptations to its unique geography, climate, and anthropogenic influences.

Covering approximately 780,000 hectares, which accounts for roughly 12% of Sri Lanka's total land area, rice cultivation represents not merely an agricultural endeavor but a symbiotic relationship between humanity and the natural environment. Particularly in the low country wet zone, where rain-fed rice lands predominate, the landscape reflects a narrative of adaptation and coexistence. However, with urbanization and increasing population pressures, the historically extensive paddy fields have experienced a gradual decline [2].

Amidst this evolving landscape, the integration of various components within the paddy ecosystem presents a compelling area of study. What drives the integration of homegardens, *Owita*, and *Kalavita* within these rice fields? Beyond their aesthetic and practical value, these elements possess significant ecological importance, promoting biodiversity and serving as economic assets. Our research aims to explore this nexus of tradition, ecology, and economics in greater depth.

Owita, a characteristic feature of the low country wet zone, holds historical significance, as reflected in village nomenclature and its strategic placement between paddy fields and settlements [3]. Similarly, *Kalavita*, resembling island-like plots within the paddy landscape, not only served practical purposes such as providing rest areas but also functioned as centers of agrobiodiversity [4]. Additionally, homegardens within rice fields presents a distinctive aspect, modifying the traditional homegarden structure to accommodate the needs of paddy cultivation [5].

This study, conducted in the Pelawaththa area of the Kalutara district, seeks to elucidate the complexities of these Riceland-associated agroecosystems. By examining the vegetation composition and agrobiodiversity of *Owita*, *Kalavita*, and Riceland-associated homegardens, it is aim to highlight their ecological significance and socio-economic relevance. Through this research, aspire to contribute to a more comprehensive understanding of the dynamic interplay between human activities and natural processes within Sri Lanka's rice cultivation landscape.

II. METHODOLOGY

Plant species within the Riceland-associated ecosystems were identified through direct observation and supplemented by information from photographs, herbariums, and field guidebooks. Species were classified based on their utility (e.g., food, timber, medicinal), origin (endemic, native, exotic), and growth form (trees, shrubs, herbs). Tree quantification was conducted by measuring the diameter at breast height (DBH) for trees with a DBH greater than 5 cm [6]. Data were collected from 10 randomly selected *Owita*, 10 *Kalavita*, and 10 homegardens in the Pelawaththa area, Kaluthara district, site were selected using Google Maps. Handheld GPS receivers recorded the GPS points, which were subsequently imported into Google Earth for polygon area measurement using built-in tools. Biodiversity indices, including the Shannon-Weiner Index, Simpson's Diversity Index, and Evenness Index, were estimated to assess species richness and distribution patterns. The Importance Value Index (IVI) was determined to evaluate the ecological significance of tree species, based on relative abundance, frequency, and dominance. Tree species composition was analyzed to identify dominant families and species, elucidating their ecological roles. Statistical analyses, including ANOVA, were performed to detect significant differences among treatment means, while architectural and canopy stratification structures were evaluated using physiognomic formulas. Data were visually represented using Microsoft Excel 2016.

III. RESULT AND DISCUSSION

A. Classification of Plant Species- Growth Habit

A total of 187 plant species were identified in homegardens, 74 species in the *Kalavita* system, and 97 species in the *Owita* system. Growth form analysis revealed significant differences among the three systems. Higher species diversity was exhibited by homegardens across most categories compared to the *Kalavita* and *Owita* systems. Notably, trees, shrubs, and herbs were the most prevalent categories across all systems (Figure 1). These findings align with previous literature, which emphasized the prominence of these growth form in homegardens [7] .

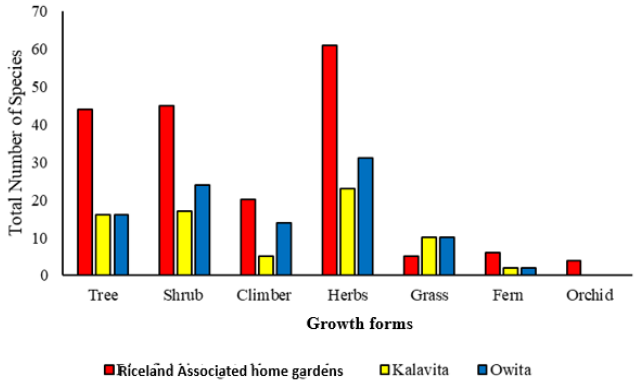


Fig 1. Growth form of Riceland-associated agroecosystems (WL1)

The architectural analysis of canopies in homegardens revealed a structured four-layer canopy, indicating careful planning and management. This layered configuration was found to enhance ecological functions and resource utilization, thereby contributing to the resilience and sustainability of the agroecosystem. Similar multi-layered canopies have been observed in traditional homegardens worldwide, emphasizing their efficiency in resource utilization and ecosystem service provision [8,9,10].

B. Origin of Species

Regarding the origin of plant species, homegardens exhibited higher diversity in exotic species compared to *Kalavita* and *Owita*. This finding underscores the role of homegardens in introducing and maintaining exotic species, contributing to overall biodiversity. Native species, however, were more prevalent homegardens and *Owita*, indicating the importance of indigenous flora in these ecosystems (Figure 2). Native plants play vital roles in ecosystem functions, cultural significance, and adaptation to local environmental conditions [11,12].

Exotic species, while enhancing species richness, can also pose challenges such as competition with native species and ecosystem disruptions. The study identified invasive species like *Dillenia suffruticosa* and *Mikania micrantha*, highlighting the need for management strategies to mitigate their impacts [13,14].

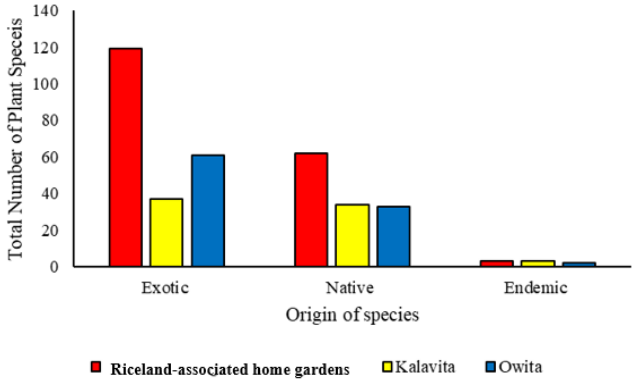


Fig 2. Origin of plant species of Riceland-associate Eco units (WL1)

C. Uses

The classification of plant species uses revealed diverse functional roles within each system. Homegardens exhibited higher abundance of species used for food, ornamental, and medicinal purposes compared to *Kalavita* and *Owita* (Figure 3). This aligns with the multifunctional nature of homegardens, serving as sources of food security, cultural heritage, and ecosystem services [15,16]. The prevalence of food crops like *Vigna unguiculata* and *Manihot esculenta* reflects the importance of homegardens in sustaining local livelihoods and dietary diversity [17].

Timber and firewood species like *Alstonia macrophylla* and *Dillenia suffruticosa* were identified, emphasizing the role of homegardens in meeting household energy needs and supporting local economies. Additionally, medicinal plants play crucial roles in traditional healthcare practices, with species like *Centella asiatica* and *Senna auriculata* being commonly used for their therapeutic properties [18].

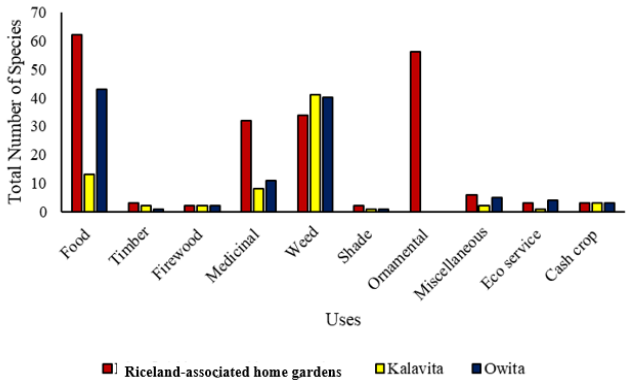


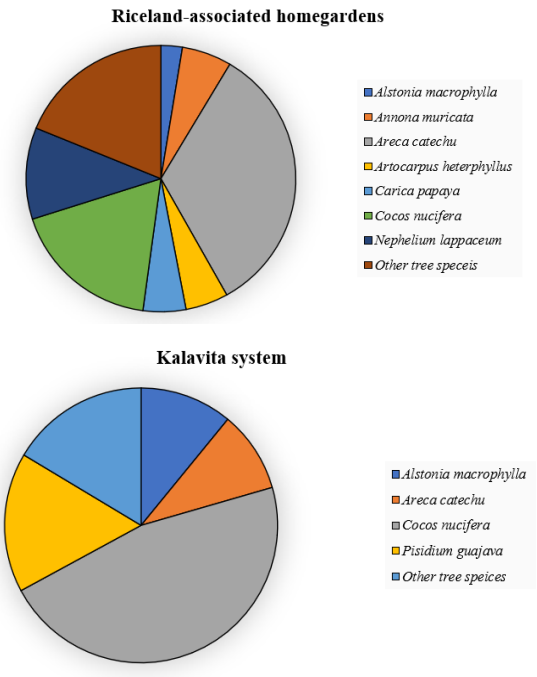
Fig 3. Plant species Uses of Riceland-associate Eco units (WL1)

Cash crops such as tea (*Camellia sinensis*) and cinnamon (*Cinnamomum verum*) contribute to income generation and economic sustainability in Riceland-associated ecosystems. The cultivation of these crops alongside food and medicinal plants enhances agrobiodiversity and resilience to market fluctuations [3].

D. Tree Species Analysis, Species Composition

The tree species composition within the Riceland-associated agroecosystems was analyzed to assess the diversity and distribution of different species. A total of 57 tree species belonging to 33 families were identified across the study sites. The dominant families included Fabaceae, Rutaceae, and Myrtaceae, accounting for 15%, 12%, and 9% of the total species, respectively (Figure 4).

Among the identified tree species, some of the most common were *Artocarpus heterophyllus* (Jackfruit), *Mangifera indica* (Mango), and *Psidium guajava* (Guava), which were found in all three types of agroecosystems. Other frequently encountered species included *Citrus sinensis* (Orange), *Cocos nucifera* (Coconut), and *Terminalia catappa* (Indian Almond) (Figure 4).



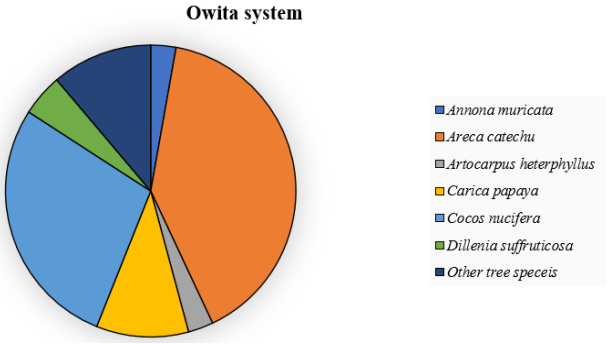


Fig 4. Tree species of Riceland-accociated agroecosystems (WL1)

E. Diversity Indices

To further characterize tree species diversity within the Riceland-associated agroecosystems, various diversity indices were estimated. The Simpson's diversity index ranged from 0.78 to 0.89 in homegardens, with a mean value of 0.84. In comparison, the *Kalavita* system exhibited Simpson's diversity index values ranging from 0.42 to 0.67, with a mean value of 0.57. Meanwhile, the *Owita* system displayed Simpson's diversity index values ranging from 0.63 to 0.79, with a mean value of 0.72.

Similarly, the Evenness index ranged from 0.63 to 0.77 in homegardens, with a mean value of 0.70. In contrast, the *Kalavita* system exhibited Evenness index values ranging from 0.36 to 0.57, with a mean value of 0.48. Meanwhile, the *Owita* system displayed Evenness index values ranging from 0.54 to 0.69, with a mean value of 0.62.

F. Importance Value Index (IVI)

The Importance Value Index (IVI) was calculated to determine the ecological significance of different tree species within the Riceland-associated agroecosystems. The IVI values varied among the dominant tree species, with *Artocarpus heterophyllus* (Jackfruit) exhibiting the highest IVI value across all three agroecosystems. Other species with significant IVI values included *Mangifera indica* (Mango) and *Psidium guajava* (Guava) (Figure 4).

The analysis of tree species composition and diversity provides valuable insights into the ecological dynamics of Riceland-associated agroecosystems. The presence of a diverse range of tree species belonging to various families highlights the richness and complexity of these traditional farming systems (Figure 4). The dominance of certain families such as Fabaceae, Rutaceae, and Myrtaceae underscores their ecological importance and potential contributions to ecosystem functioning. These families are known for their economic value, as many species within them produce fruits, timber, or medicinal products.

The estimation of diversity indices, including Simpson's diversity index and Evenness index, further elucidates the distribution and evenness of tree species within the agroecosystems. Higher diversity indices observed in homegardens compared to the *Kalavita* and *Owita* systems indicate the importance of homegarden agroforestry in supporting tree species diversity.

The Importance Value Index (IVI) analysis highlights the ecological significance of certain tree species within the agroecosystems. Species with higher IVI values, such as *Artocarpus heterophyllus* (Jackfruit), may play key roles in ecosystem functioning and provide various ecosystem

services such as shade, soil stabilization, and habitat for wildlife [19].

The tree species analysis underscores the importance of conserving and promoting tree diversity within Riceland-associated agroecosystems. Enhancing tree species richness and evenness can contribute to ecosystem resilience, agroecological sustainability, and the livelihoods of local communities. Conservation strategies aimed at protecting indigenous tree species and promoting agroforestry practices are therefore essential for maintaining biodiversity and ecosystem services within these traditional farming systems [20].

G. Tree Diversity

The tree diversity within the Riceland-associated agroecosystems was assessed using the Shannon-Wiener index. The size of the homegardens averaged 0.12 ha, while *Owita* averaged 0.25 ha, and *Kalavita* averaged 0.08 ha. While measuring biodiversity, it's important to consider the entire eco-unit as the ecological context. Even if the size varies, the management practices, vegetation, and overall habitat quality within each unit will affect biodiversity. The Shannon-Wiener index values ranged from 1.77 to 2.32 in homegardens, with a mean value of 2.00. In comparison, the *Kalavita* system exhibited Shannon-Wiener index values ranging from 0.30 to 1.54, with a mean value of 1.16. Meanwhile, the *Owita* system displayed Shannon-Wiener index values ranging from 1.12 to 1.67, with a mean value of 1.44 (Table 01).

TABLE 1. TREE DIVERSITY CHARACTERISTICS IN DIFFERENT CATEGORIES OF RICELAND-ASSOCIATED AGROECOSYSTEM OF LOWLAND WET ZONE OF PELAWATHTHA AREA IN SRI LANKA

Rice field agroecosystem size	**Species recorded per agroecosystem**		**Shannon Wiener index**	
	Total	**Mean**	**Mean ± SE**	**Range**
Riceland-associated homegardens	23	10.8	2.00±0.1	1.77-2.32
Kalavita system	12	4.2	1.16±0.23	0.30-1.54
Owita system	15	5.8	1.44±0.09	1.22-1.67

SE: Standard Error

When considering the significance of tree plant diversity among the Riceland-associated ecosystems, a statistical analysis revealed a significant difference (p-value 0.008). The mean Shannon-Wiener index value was highest in the homegardens (2.00), followed by the *Owita* system (1.44), and the *Kalavita* system exhibited the lowest value (1.16) (Table 01). However, there was non- significant difference between the *Kalavita* and *Owita* systems (p-value 0.288). There was also a significant difference observed between the *Kalavita* system and homegardens (p-value 0.012). Additionally, compared with homegardens and the *Owita* system, a significant difference was observed (p-value 0.005) (Figure 5).

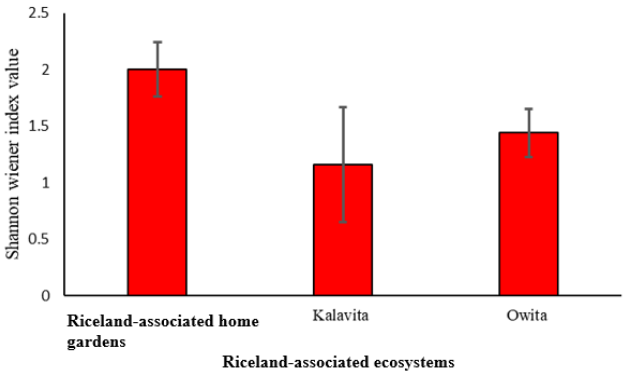


Fig 5. Mean Shannon Wiener index value on Riceland-associated agroecosystems (WL1)

The findings regarding tree biodiversity within the Riceland-associated agroecosystems underscore the ecological richness and complexity of these traditional farming systems. The higher tree diversity observed in homegardens compared to the *Kalavita* and *Owita* systems reflects the intricate ecological dynamics and management practices within these agroecosystems (Figure 5).

The significant difference in tree diversity among the Riceland-associated ecosystems highlights the varying degrees of ecological resilience and sustainability conferred by different agricultural practices. Riceland-associated homegardens, characterized by their multi-layered canopy configurations and diverse species admixtures, provide favorable conditions for enhanced tree diversity. The careful structuring and management of homegardens, with strategic placement of different tree species, contribute to the observed higher biodiversity [5].

The lower tree diversity observed in the *Kalavita* system may be attributed to differences in agricultural practices and land management strategies. *Kalavita* systems, characterized by their smaller size and potentially more intensive cultivation practices, may limit the establishment and maintenance of diverse tree species. In contrast, *Owita* systems, with their larger size and potentially more extensive land use patterns, may offer greater opportunities for supporting diverse tree communities.

The lack of significant difference in tree diversity between the *Kalavita* and *Owita* systems suggests that factors beyond land size alone may influence tree diversity. Other variables such as management intensity, land use history, and cultural practices may also play crucial roles in shaping tree diversity within these agroecosystems.

The findings emphasize the importance of traditional agroecosystems like Riceland-associated homegardens in conserving and promoting tree diversity. These systems not only contribute to agricultural productivity and food security but also harbor valuable ecological resources essential for maintaining ecosystem health and resilience. Conservation and sustainable management of these agroecosystems are therefore vital for safeguarding biodiversity and supporting the livelihoods of local communities.

IV. CONCLUSION

Riceland-associated homegardens in Pelawatta, Kaluthara district, Sri Lanka, exhibit higher species diversity and ecological functionality compared to *Kalavita* and *Owita*

systems. These homegardens support a rich array of trees, shrubs, and herbs, structured in a four-layer canopy that enhances resource utilization and ecological services. The multifunctionality of these gardens, providing food, medicinal plants, timber, and firewood, underscores their role in sustaining local livelihoods and cultural heritage. The presence of economically valuable cash crops further adds to their resilience. Dominant tree families such as Fabaceae, Rutaceae, and Myrtaceae play crucial roles in ecosystem stability. The significant biodiversity in these agroecosystems highlights the importance of agroforestry practices. Sustainable management and conservation strategies are essential to maintain this biodiversity, ensuring the ecological and economic sustainability of these traditional farming systems.

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REFERENCES

[1]Bandara, M., 2009. Exploring the link between culture and biodiversity in Sri Lanka. SANSAI: An Environmental Journal for the Global Community, 4, pp.1-23.

[2]Kotagama, S.W. and Bambaradeniya, C.N.B., 2006. An overview of the wetlands of Sri Lanka and their conservation significance. National Wetland Directory of Sri Lanka, pp.7-16.

[3]Dunusinghe P and Manawadu L (2018)., An inquiry to value chains of agrobiodiversity products: evidence from three identified ecosystems, in proceeding of the Wayamba international conference (WinC 2018), 24-25 August 2018, PP 318

[4] Bell, H.C.P., 1883. Sinhalese Customs and Ceremonies Connected with Paddy Cultivation in the Low-Country. The Journal of the Ceylon Branch of the Royal Asiatic Society of Great Britain & Ireland, 8(26), pp.44-93.

[5]Bambaradeniya, C.N., 2003, December. Traditional home garden and rice agro-ecosystems in Sri Lanka: An integrated managed landscape that sustains a rich biodiversity. In Proceedings of the International Symposium on perspectives of the biodiversity research in the western pacific and Asia in the 21st Century, Organized by Diversitas in Western Pacific and Asia (DIWPA), Kyoto, Japan.

[6]Conti, G., Gorne, L.D., Zeballos, S.R., Lipoma, M.L., Gatica, G., Kowaljow, E., Whitworth-Hulse, J.I., Cuchietti, A., Poca, M., Pestoni, S. and Fernandes, P.M., 2019. Developing allometric models to predict the individual aboveground biomass of shrubs worldwide. Global Ecology and Biogeography, 28(7), pp.961-975.

[7]Hitinayake, H.M.G.S.B. and Sinclair, F.L. (1996). Categorizing complex agroforestry practices for Farming systems research and extension (FSR/E): the case of forestgardens in Kandy district. Proc. of the 14th International symposium on sustainable farming systems. 11-16 November, 1996.

[8] Jensen, M., 1993. Soil conditions, vegetation structure and biomass of a Javanese home garden. Agroforestry Systems, 24(2), pp.171-186.

[9] De Clerck, F.A. and Negreros-Castillo, P., 2000. Plant species of traditional Mayan homegardens of Mexico as analogs for multistrata agroforests. Agroforestry Systems, 48(3), pp.303-317.

[10] Mohri, H., Landreth, N., Lahoti, S. Saito, O., Hitinayake, G., Gunatilleke, N., Irham, Van Thang, H. and Takeuchi, K. (2018). Ecosystem Services of Traditional Homegardens in South and Southeast Asia. In Resilient Asia: Fusion of Traditional and Modern Systems for a Sustainable Future. (eds.) Takeuchi, K., Saito, O., Matsuda, H. and Mohan. G. Springer Japan. pp. 95-122.

[11] Gunawardene, N.R., Daniels, A.E., Gunatilleke, I.A.U.N., Gunatilleke, C.V.S., Karunakaran, P.V., Nayak, K.G., Prasad, S., Puyravaud, P., Ramesh, B.R., Subramanian, K.A. and Vasanthy, G., 2007. A brief overview of the Western Ghats--Sri Lanka biodiversity hotspot. Current Science (00113891), 93(11).

[12] Marambe[1], B., Pushpakumara[1], G. and Silva, P., 2009. Biological diversity in lowland rice fields: Sri Lankan context.

Weber, E., 2017. Invasive plant species of the world: a reference guide to environmental weeds. Cabi.

[13] Mollot, G., Pantel, J.H. and Romanuk, T.N., 2017. The effects of invasive species on the decline in species richness: a global meta-analysis. In Advances in ecological research (Vol. 56, pp. 61-83). Academic Press.

[14] Senanayake, R.L., Sangakkara, U.R., Pushpakumara, D.K.N.G. and Stamp, P., 2009. Vegetation composition and ecological benefits of home gardens in the Meegahakiula region of Sri Lanka.

[15] Karlen, D.L. and Rice, C.W., 2015. Soil degradation: Will humankind ever learn?. Sustainability, 7(9), pp.12490-12501.

Wekumbura, W.G.C., Mohotti, A.J., Frossard, E., [16] [16]Kudagammana, S.T. and Silva, K.D.R.R., 2017. Prospects and Issues Related to Tea Cultivation in Mid Country Home garden Based Tea Smallholdings in a Selected Village in Sri Lanka. Tropical Agricultural Research, 28(4), pp.503-516.

[17] Ruwanmali, W.M.D., Eeswara, J.P. and Ratnayake, R.H.M.K., 2016. Antioxidant properties and mineral contents of selected plant species used in green leafy porridge Kola kenda.

[18] Dagar, J. C., & Tewari, J. C. (2016). Agroforestry research developments: anecdotal to modern science. Agroforestry research developments. Nova Publishers, New York, 1-45.

[19] Tadesse, E., Negash, M., & Asfaw, Z. (2021). Impacts of traditional agroforestry practices, altitudinal gradients and households' wealth status on perennial plants species composition, diversity, and structure in south-central Ethiopia. Agroforestry Systems, 95(8), 1533-1561.

Amphibian Diversity as an Indicator of Ecosystem Maturity: Comparative Studies in Five Different Ecological Seral Stages at the Belipola Analog Forest, Sri Lanka

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***Abstract*—Amphibians serve as vital bioindicators of environmental health due to their sensitivity to habitat changes. Forest degradation threatens their habitats, but analog forestry an ecosystem restoration method can both restore habitats and provide economic benefits while conserving amphibians and other biodiversity. This study explores amphibian diversity across five seral stages in the Belipola Arboretum, the first analog forest in Sri Lanka. Stratification and canopy cover were assessed using a physiognomic formula. The study was conducted across five distinct seral stages, encompassing early, mid, and late seral stages of ecological succession. Using the Visual Encounter Survey method, 120 amphibians from 13 species across four families were recorded. Data analysis with SAS tools showed that 85% of species were endemic, and 54% were threatened (Critically Endangered, Endangered, or Vulnerable). Statistical analysis revealed no significant differences in biodiversity between the early stages (p-values: first vs. second = 0.1478, second vs. third = 0.0678, third vs. fourth = 0.2055, fourth vs. fifth = 0.0609). However, significant differences were found between other stages. The highest Shannon-Wiener index, indicating greater biodiversity, was in the fifth seral stage (1.82), followed by the fourth (1.31), third (0.98), second (0.49), and first (0.11) stages. These results show that amphibian biodiversity increases significantly after the second seral stage, with habitat quality improving as succession progresses. This suggests that analog forestry, which mimics natural forest structures, enhances habitat quality and supports biodiversity conservation. As ecological succession advances, habitat quality for threatened amphibians improves, highlighting the value of maintaining and restoring diverse ecosystems. The study supports analog forestry as an effective approach for promoting ecological health and biodiversity in forested landscapes.**

Keywords—Amphibian biodiversity, Biodiversity assessment, Conservation management, Habitat restoration

I. INTRODUCTION

Amphibian species can offer valuable insights into biodiversity and vegetation quality due to their unique biology and ecological requirements. Amphibians are often considered bioindicators of environmental health because they are highly sensitive to changes in their habitat quality. Therefore, monitoring amphibian populations can provide early warnings of environmental degradation [1].

Understanding the relationships between amphibians and habitat quality is crucial for effective conservation and management of ecosystems. Conservation efforts aimed at protecting amphibian habitats can have broader benefits for biodiversity conservation, ecosystem functioning, and human well-being [2].

Forest degradation, such as deforestation and habitat fragmentation, reduces the availability of suitable habitat for amphibians. Many amphibian species rely on forested areas for breeding, foraging, and shelter. Especially in Sri Lanka where there are large numbers of amphibians that have direct development, such as *Pseudophilautu* spp require phylotelomata for breeding. When forests are cleared or fragmented, populations become isolated, increasing the risk of genetic depression and increasing the risk of local extinctions. Forests provide a stable microclimate with relatively consistent temperature, humidity, and light conditions, which are critical for amphibian survival and reproduction. Forest degradation can lead to changes in microclimate, such as increased temperature extremes, reduced humidity, and altered light levels, which may negatively impact amphibian physiology, behavior, and reproductive success [3].

This study was conducted a comprehensive baseline survey of amphibian biodiversity of the Belipola Arboretum, including species richness, abundance, and distribution across different habitat types and seral stages. Also, a second objective was implementing long-term monitoring protocols to track amphibian populations and biodiversity that can be associated with the different seral stages over multiple years or decades. As well as to define clear criteria for classifying different seral stages of ecological succession within any tree dominated

ecosystem. This may involve assessing the physiognomic status, vegetation composition, habitat structure, disturbance history, and other relevant factors. Furthermore, it evaluates habitat quality and suitability for amphibians at each seral stage.

Future studies should focus on individual amphibian species or groups to understand their habitat preferences, and responses to ecological succession. This can provide insights into how different species respond to changes in habitat structure and environmental conditions and utilize this in setting parameters for valuing biodiversity.

II. METHODOLOGY

A. Study Area

The study was undertaken in Belipola. The Belipola Arboretum is a significant conservation and research initiative located in Sri Lanka. It serves as an educational facility and a hub for biodiversity conservation efforts in the region. The Belipola Arboretum is situated in the Central Highlands of Sri Lanka, near the town of Bandarawela (longitude 80 93397 E, latitude 6 87515 N) in the Badulla District. This area is known for its rich biodiversity and unique montane forest ecosystems. Agro ecological zone – Up country intermediate zone (IM1). Temperature -17.5 -20 °C and Rainfall -1500-2000 mm.

B. Sampling And Data Collecting Method

Based on the analog forestry practitioner's guide, the architectural structure of different seral stages in Belipola analog forest was determined and schematic diagrams were drawn by using the physiognomic formula [4]. Stratification and canopy cover were identified and seral stages were determined according to the schematic diagram. Five different seral stages representing early seral stage, mid-seral stage, and late seral stage were selected for the study. Plant community complexity, stratification, and canopy coverage increase from the 1st to the 5th seral stage. These five seral stages are named as the 1st seral stage, 2nd seral stage, 3rd seral stage, 4th seral stage, and 5th seral stage, along with their growth form, stratification, and cover. A 25-meter transect was established at each seral stage to systematically study amphibian diversity and evaluate the impact of seral stage progression on amphibian communities.

Visual Encounter Survey (VES) is a common method that was used to estimate the abundance or presence of amphibian species. VES survey was conducted during the rainy season were periods of increased amphibian activity. Late evening and night time at 7.00-10.00 PM time was conducted when many amphibian species are most active during the late evening and night time. The research conducted from April 2024 to June 2024. Systematic scanning of the environment for amphibians was carried out along pre-determined transects or search areas within the survey site. Visual cues were used to identify amphibians, including direct sight of individuals, or other signs such as calls or vocalizations.

The collected data was analyzed to estimate amphibian abundance, species richness, and diversity (Shannon-Weiner Species Diversity Index). Data analysis may involve SAS statistical tools and software to interpret the results accurately.

III. RESULT AND DISCUSSION

A. Amphibian Species In Belipola Analog Forest

A total of 120 individuals of amphibians belong to 13 species for 04 families were recorded during the study. A total of 13 different amphibian species were identified in the all-seral stages A total 0f 03 amphibian species in the 1st seral stage, 04 amphibian species in 2nd seral stage, 06 amphibian species in 3rd seral stage, 09 amphibian species in 4th seral stage and 12 in 5th seral stage were identified (Figure 1).

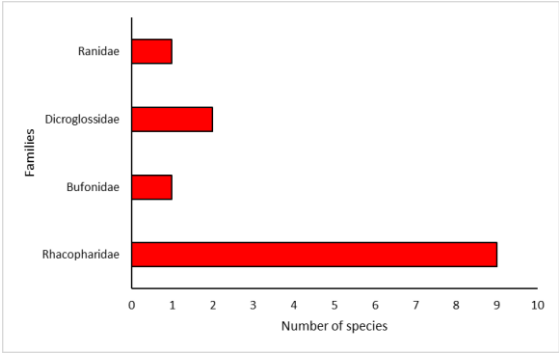

Fig 1. Number of amphibian species in different Families

The total number of amphibian species increases rapidly after the third seral stage, and this increase is closely related to the process of seral succession (Table 1). The relationship between amphibian species growth and seral succession could suggest that the development or changes in the ecosystem during the third seral stage are particularly favorable for amphibians, leading to their rapid increase in diversity [5].

TABALE 1. AMPHIBIAN SPECIES IN BELIPOLA ANALOG FOREST

Scientific name	**1st seral stage**	**2nd seral stage**	**3rd seral stage**	**4th seral stage**	**5th seral stage**
Pseudophilautus cf. alto	+	+	+	+	+
Pseudophilautus popularis	+	+	+	+	+
Pseudophilautus fulvus		+	+		+
Pseudophilautus microtympanum			+	+	+
Pseudophilautus fergusonianus			+	+	+
Pseudophilautus schneideri				+	
Pseudophilautus folicola				+	+
Polypedates eques				+	+
Polypedates cruciger				+	+
Minervarya kirtisinghei		+			+
Minervarya agricola					+
Duttaphrynus melanostictus	+		+		+
Hylarana temporalis				+	+

B. Amphibian Species Dynamics and Endemic Dominance

Out of a total of 13 amphibian species, 11 endemic species have been recorded in the study (Figure 2). This is 85% of all recorded amphibian species. A total of 02 amphibian species have been recorded as native species which is 15% of all amphibian species recorded.

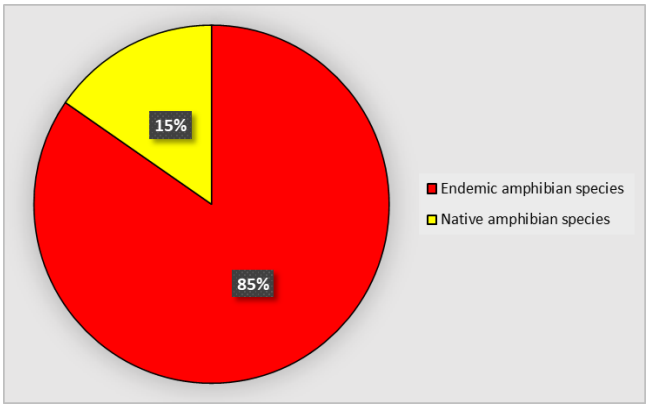

Fig 2. Parentage of native and endemic amphibian species in Belipola analog forest

All recorded amphibian species of the family Rhacophoridae and Ranidae were endemic to Sri Lanka (Figure 1). The family Rhacophoridae, commonly known as tree frogs or shrub frogs, is particularly diverse in Sri Lanka. These frogs are well adapted to arboreal habitats particularly in late seral succession stages of forest development. Late seral stages represent mature, stable forests with a complex canopy structure and diverse understory vegetation. These habitats provide abundant opportunities for arboreal frogs to thrive due to the availability of perching sites, shelter, and prey. They have adhesive toe pads that enable them to grip onto vegetation, allowing them to move easily among branches and leaves. This adaptation is crucial for their arboreal lifestyle, as it helps them avoid predators, locate prey, and navigate their environment [3,6].

The presence of these frogs in late seral forests indicates the health and complexity of the ecosystem, as they are sensitive to habitat disturbance and rely on mature vegetation for their survival. Protecting and conserving these late seral habitats is essential for maintaining populations of *Pseudophilautus* frogs and other species that depend on them [7].

C. The Conservation Status Of Amphibians In Belipola

Out of a total of 13 amphibian species, 02 critically endangered (CR) endemic species (*Pseudophilautus fulvus* and *Pseudophilautus microtympanum*) have been recorded. A total of 02 endangered (EN) amphibian species (*Polypedates eques* and *Pseudophilautus schneideri*) have been recorded which is 15% of all amphibian species recorded. A total of 03 vulnerable (VU) amphibian species (*Pseudophilautus fergusonianus*, *Pseudophilautus folicola*, and *Minervarya kirtisinghei*) have been recorded which 23% of all amphibian species recorded. *Pseudophilautus popularis* and *Hylarana temporalis* have been recorded and which Near Threatened species amphibian species in the study. Out of a total 13 amphibian species 07 threatened species (CR, EN and VU) have been recorded which is 54% out of all amphibian species recorded (Table 2).

TABLE 2. THE CONSERVATION STATUS OF AMPHIBIAN SPECIES IN BELIPOLA ANALOG FOREST

Scientific name	**1st seral stag**	**2nd seral stage**	**3rd seral stage**	**4th seral stage**	**5th seral stage**
Pseudophilautus cf. alto	NA	NA	NA	NA	NA
Pseudophilautus popularis	NT	NT	NT	NT	NT
Pseudophilautus fulvus		CR	CR		CR
Pseudophilautus microtympanum			CR	CR	CR
Pseudophilautus fergusonianus			VU	VU	VU
Pseudophilautus schneideri				EN	
Pseudophilautus folicola				VU	VU
Polypedates eques				EN	EN
Polypedates cruciger				LC	LC
Minervarya kirtisinghei		VU			VU
Minervarya agricola					LC
Duttaphrynus melanostictus	LC		LC		LC
Hylarana temporalis				NT	NT

CR: Critically Endangered
EN: Endangered
VU: Vulnerable
NT: Near Threatened
LC: Least Concern
NA : Not Applicable

Late seral stages often have a more complex and diverse habitat structure compared to early stages. They may contain a variety of microhabitats, such as fallen logs, leaf litter, and dense vegetation, which provide ample hiding places, breeding sites, and foraging opportunities for threatened amphibian species [8].

Understanding the habitat preferences of threatened amphibian species, including their affinity for late seral succession stages, is crucial for effective conservation planning and management. Protecting and restoring mature forest ecosystems, maintaining habitat connectivity, and mitigating threats such as habitat loss and fragmentation are essential strategies for safeguarding these threatened amphibian species and their habitats [9].

D. Amphibian Biodiversity Across Seral Stages

When the amphibian biodiversity is considered, there is not a significant difference between 1st seral stage and 2nd seral stage (p-value-0.1478), 2nd seral stage and 3rd seral stage(p-value-0.0678), 3rd seral stage and 4th seral stage(p-value-0.2055), 4th seral stage and 5th seral stage(p-value-0.0609). There are significant differences among all the other seral stages (Table 6). The highest mean value shows the 5th seral stage (1.82) followed by 4th seral stage (1.31), 3rd seral stage (0.98), and 2nd seral stage (0.49). The least value is shown in the 1st seral stage (0.111) (Table 3 Figure 4).

TABLE 3. P-VALUES FOR MEAN COMPARISON OF AMPHIBIAN SPECIES DIVERSITY

	1st seral stage	2nd seral stage	3rd seral stage	4th seral stage	5th seral stage
1st seral stage		0.1478	0.0026	0.0001	<.0001
2nd seral stage	0.1478		0.0678	0.0041	<.0001
3rd seral stage	0.0026	0.0678		0.2055	0.0036
4th seral stage	0.0001	0.0041	0.2055		0.0609
5th seral stage	<.0001	<.0001	0.0036	0.0609	

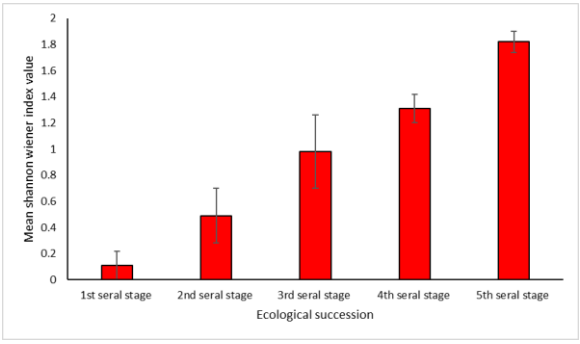

Fig 4. Mean Shannon Wiener index value on 1st to 5th seral stages

E. Relationship Of Amphibian Biodiversity With Ecological Successional Stages

Amphibian species biodiversity was exhibited exponential growth after the second seral stage and has a notable relationship with seral succession (Figure 5).

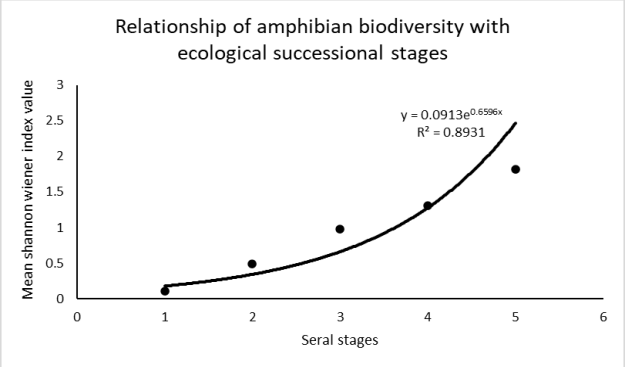

Fig 5. Relationship of amphibian biodiversity with ecological successional seral stages

In the early stages of seral succession, habitat conditions may not yet be optimal for supporting a diverse amphibian community. As succession progresses and vegetation becomes more established, habitat complexity increases. The development of diverse microhabitats, such as leaf litter, fallen logs, and shrubby areas, provides a wider range of niches for amphibians, leading to an exponential increase in biodiversity. With the progression of seral succession, there is typically an increase in the availability of resources such as food, shelter, and breeding sites. This abundance of resources can support larger populations of amphibians and facilitate the colonization of new species, contributing to the observed growth in biodiversity [10].

Late seral stages offer more stable environmental conditions, including temperature and moisture levels, which are favorable for amphibian survival and reproduction. This stability reduces physiological stress on amphibians and enhances their overall fitness, allowing populations to thrive and biodiversity to increase. As seral succession advances, interactions between amphibians and other organisms within the ecosystem become more complex. For example, as vegetation matures, it provides habitat and food for a variety of invertebrates, which in turn serve as prey for amphibians. These intricate ecological interactions can promote species coexistence and biodiversity [10].

Understanding the relationship between amphibian biodiversity and seral succession is crucial for effective conservation and habitat management. Conservation efforts should aim to maintain and restore diverse seral stages within landscapes to support a rich and resilient amphibian community. Additionally, monitoring amphibian populations across different seral stages can provide valuable insights into ecosystem health and the effectiveness of conservation interventions [11].

IV. CONCLUSION

The study highlights that ecosystem changes during the second seral stage significantly enhance amphibian diversity, with exponential growth in species richness observed in subsequent stages. Late-seral stages contribute even further to amphibian diversity by introducing greater habitat complexity compared to early and mid-seral stages. Notably, 11 out of 13 recorded amphibian species are endemic, underscoring the unique ecological conditions and high levels of regional biodiversity within these ecosystems. However, the critical conservation needs are evident, as nearly 54% of amphibian species are threatened, underscoring the urgent need for targeted conservation strategies to protect these vulnerable species and their habitats.

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REFERENCES

[1] Hocking, D.J. and Babbitt, K.J., 2014. Amphibian contributions to ecosystem services. Herpetological conservation and biology.

[2] Beebee, T.J. and Griffiths, R.A., 2005. The amphibian decline crisis: a watershed for conservation biology?. Biological conservation, 125(3), pp.271-285.

[3] Meegaskumbura, M., Senevirathne, G., Manamendra-Arachchi, K., Pethiyagoda, R., Hanken, J. and Schneider, C.J., 2019. Diversification of shrub frogs (Rhacophoridae, Pseudophilautus) in Sri Lanka–Timing and geographic context. Molecular Phylogenetics and Evolution, 132, pp.14-24.

[4] Senanayake, R., Realizing the Value of Photosynthetic Biomass: The Role of Analog Forestry.

[5] deMaynadier, P.G. and Hunter Jr, M.L., The relationship between forest management and amphibian ecology.

[6] Meegaskumbura, M., Meegaskumbura, S., Bowatte, G., Manamendra-Arachchi, K., Pethiyagoda, R., Hanken, J. and Schneider, C.J., 2010. Taruga (Anura: Rhacophoridae), a new genus of foam-nesting tree frogs endemic to Sri Lanka.Miththapala, S., 2015. Conservation revisited.

[7] Hamer, A.J. and McDonnell, M.J., 2008. Amphibian ecology and conservation in the urbanising world: a review. Biological conservation, 141(10), pp.2432-2449.

[8] Marcot, B.G., Pope, K.L., Slauson, K., Welsh, H.H., Wheeler, C.A., Reilly, M.J., Zielinski, W.J., Spies, T.A., Stine, P.A., Gravenmier, R. and Long, J.W., 2018. Other species and biodiversity of older forests. Synthesis of science to inform land management within the Northwest Forest Plan area, pp.371-459.

[9] Swanson, M.E., Franklin, J.F., Beschta, R.L., Crisafulli, C.M., DellaSala, D.A., Hutto, R.L., Lindenmayer, D.B. and Swanson, F.J., 2011. The forgotten stage of forest succession: early-successional ecosystems on forest sites. Frontiers in Ecology and the Environment, 9(2), pp.117-125.

[10] Kunz, B.K., Waddle, J.H. and Green, N.S., 2019. Amphibian monitoring in hardwood forests: Optimizing methods for contaminant•based compensatory restorations. Integrated Environmental Assessment and Management.

Sustainable Agriculture, Environment (Food)

Postharvest Weight Loss Assessment of Leeks from Farmgate to The Retailer Market in Sri Lanka: A Case Study in Nuwara Eliya District

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Abstract—Leeks is a significant vegetable crop in Sri Lanka, primarily cultivated in the upcountry region. After harvest, these perishable vegetables are transported to various parts of the country and even to foreign markets. During their journey along the market chain in the wet zone, yield losses can occur from the farmer's field to the retailer's market. This study was conducted to measure the yield loss of leeks along this market chain and to identify specific factors contributing to this reduction. Random samples of harvested leeks (Mesh bags) were collected from the field, wholesale markets in Nuwara Eliya and Meegoda, and retail markets in Colombo to analyze the market chain. Weights were measured at each location, and postharvest practices like handling, packing, and transporting were observed and discussed with stakeholders. The study revealed that the total yield loss along the market chain was 40.09% by weight. A substantial portion of this loss, 78.98%, occurred during transportation to the retailer market and afterward, during the sorting and cleaning processes. Given the high level of yield loss, it is crucial to implement strategies to minimize these losses at each stage of the market chain to reduce economic losses for individuals and the nation.

Keywords—Leeks, Postharvest life, Transportation, Packaging

I. INTRODUCTION

Leeks *(Allium ampeloprasum)* is a leafy vegetable that belongs to the family Amaryllidaceae. It is a biennial plant grown for its blanched stems and leaves. Leeks are well known for their distinct flavor and therapeutic benefits resulting from the presence of higher levels of phytochemicals, bioactive substances, and good nutritional qualities. They are consumed raw in salads or cooked as a flavoring in soups and stews [1]. Green leaves and the white base of the raw leek are used as the edible portion while some use the light green portion of the stem in consumption. This raw leek is considered a perishable vegetable for its higher composition of water and nutrients in the edible portion of the crop. It is widely grown in upcountry areas under cool climates such as Nuwara Eliya and Badulla as the cool climate affects the thickness of the stem [2]. Sri Lanka produced 51,800 tons of leeks in 2022. This represents a 15.8% increase over the prior year. It is about 20-30 tons/ha of leeks are in cultivation at present.

Because of their unique structure, shape, and delicate feel together with their high moisture content, leeks are more

prone to physical and mechanical damage throughout the marketing chain. Inadequate road accessibility, excessive climate fluctuation, and inadequate infrastructural amenities would exacerbate losses during transit while environmental factors including temperature, O_2 concentration, and relative humidity can start several reaction pathways that might cause leeks to deteriorate [3]. Due to this, quantitative and qualitative losses can be incurred from the farmer fields up to the consumer level along the market chain. It was found 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 [4].

As a tropical developing country, Sri Lanka faces conditions that can exacerbate these challenges. The main stages of the postharvest supply chain involved with the research showed, how it contributed to the loss of quality and quantity of the leeks. Furthermore, the management practices used by the farmers, pre-harvesting strategies, and pest and disease management also affect the quality loss of the crop. This study shows the causes of postharvest losses of leeks in the wet zone region of Sri Lanka to identify suitable preventive measures and provide achievable strategies.

II. METHODOLOGY

A half-hectare farm that contributes aiming different target markets was chosen in the Nuwara Eliya district, Sri Lanka. The basic type of soil observed in Nuwara Eliya is red-yellow podzolic soil where the crop leeks are also grown. Long summer type varieties (Jambo variety) were cultivated in large areas separated plot-wise. The cool climatic condition of Nuwara Eliya affects the stem thickness of leeks to grow well. Random samples (mesh bags/poly-sack bags filled with harvested leeks) were selected from the total harvest and tracked at each point of the market chain, including the field (Nuwara Eliya Mahagasthota), wholesale market (Nuwara Eliya and Meegoda economic markets), and retail market (Colombo), to collect data (Fig 1). The total number of mesh bags harvested at the farmers' field was 25 but only 15 of the bags were tracked until the end point of the market chain. The weight of the yield was measured as the weight per bag at each location in the market chain using a weighing balance and the loss at each location as a proportion of the total loss was calculated. Information on postharvest practices such as harvesting, handling, packing, transporting, and sorting was observed visually and obtained through verbal communication with stakeholders.

III. RESULTS AND DISCUSSION

The harvested leeks were sorted and cleaned, packed in mesh bags on the farm, and transported by truck to the wholesale market (Fig. 2). In the selected farm, the plots were divided aiming at the target market, and postharvest practices were conducted according to market requirements. Depending on the final destination of the wholesale market, cleaning methods, and sorting strategies varied. Leeks harvested on the farm were planned to reach four markets: the export market (Maldives), the Dambulla economic center, the Puttalam market, and the Meegoda economic center. Here the observations and data were collected from the field to the Meegoda economic center and thereafter to the retail market to track the postharvest losses in the market chain. There was no cleaning process after harvesting from the farm. Leeks were uprooted well, and soil was dusted when the target markets were Meegoda, Badulla, and Puttalam. The crops aimed at the export market were washed from the water ponds close to the farm. The bundled leeks were packed tightly in mesh bags and loaded on the lorry. Even though the distance from the farm to the Nuwara Eliya economic center is less, leeks were exposed to many surfaces for measuring purposes and the cleanliness of the markets affected the harvested crops.

According to the current study, a 9.19% yield loss from the total loss occurred while transporting from the farm field to the Nuwara Eliya economic center and the distance between these two locations was 3.9 km. On the other hand, a yield loss of 11.84% was observed during transportation from the Nuwara Eliya economic center to the Meegoda economic center and the distance was 140 km (Fig 3). Therefore, it could be stated that a considerable yield loss occurred during transportation due to poor handling of the harvested leeks. Leeks are farmed in upcountry locations and brought to urban areas which are located far away from the farmer fields [3]. Produce loss during transportation is mostly caused by inadequate refrigeration, bad infrastructure, loading and unloading procedures, and inadequate transportation methods [5]. Similarly, in the current study, proper handling practices for harvested leeks were not found. Therefore, necessary steps should be taken to reduce losses during transportation.

Due to the varying lengths of available leek cultivars, the current packaging is inadequate for shipping, necessitating the use of polypropylene sacks (poly-sacks). Physical damage, including surface injuries, impact, bruising, and vibration, can cause product degradation due to the use of these types of improper packing materials. The Sri Lankan vegetable sector incurred yearly postharvest losses of 15.7% owing to the usage of poly-sacks for transporting leeks [3]. Farmers typically use poly-sacks to store vegetables. However, if these sacks are not ventilated properly, heat can build up inside, leading to both toughness and wilting of the vegetables [6].

The current study showed that the yield loss of leeks along the mentioned market chain was 40.07%. From the total loss, a considerable loss occurred during transportation, cleaning, and sorting at the retailer's shops which accounted for 78.98%. Large-scale temperature and

humidity-controlled storage facilities are currently unavailable as a service. During a glut of local supplies, farmers, collectors, wholesalers, and retailers discard excess vegetables as rubbish, resulting in harvest waste [6]. This wastage was more at the retailer level when it comes to the current study. Inadequate storage facilities in the downstream chain hinder successful sorting and grading processes. An inadequate understanding of temperature requirements, and cold chain protocols can lead to unfavorable outcomes in leeks postharvest handling [5].

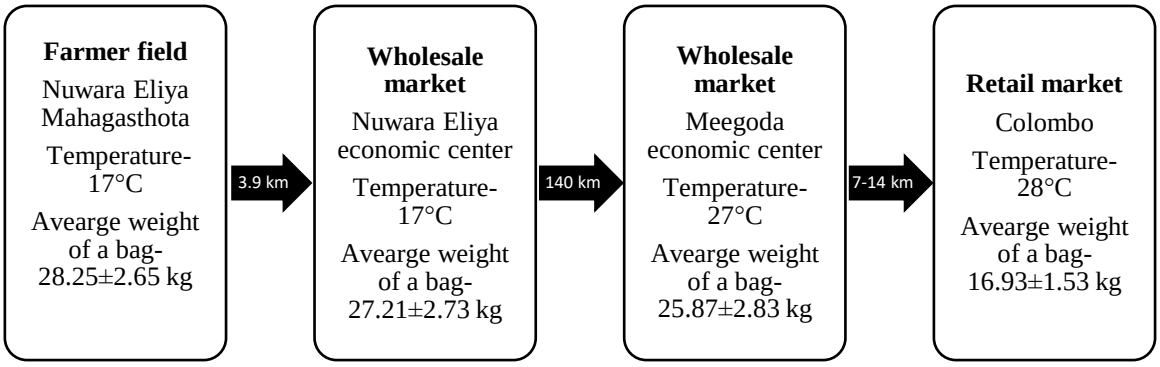

Fig. 1. Each stage's location details, distances, and average leek weight per bag (mean ± Standard Deviation of 15 replicates) along the market chain.

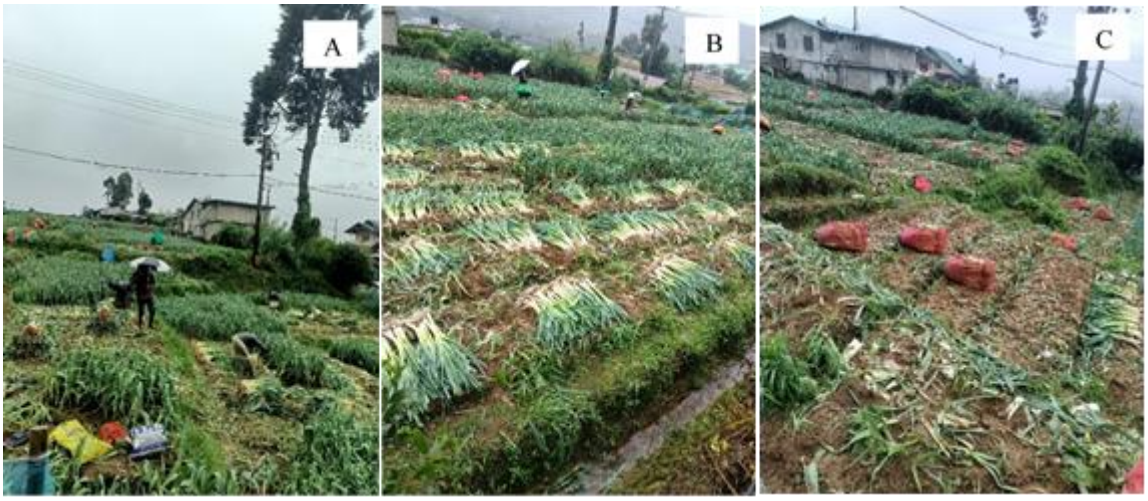

Fig. 2. (A. Farmer field at Nuwara Eliya, B. Harvested leeks kept on the same plot, C. Leeks filled mesh bags at the field)

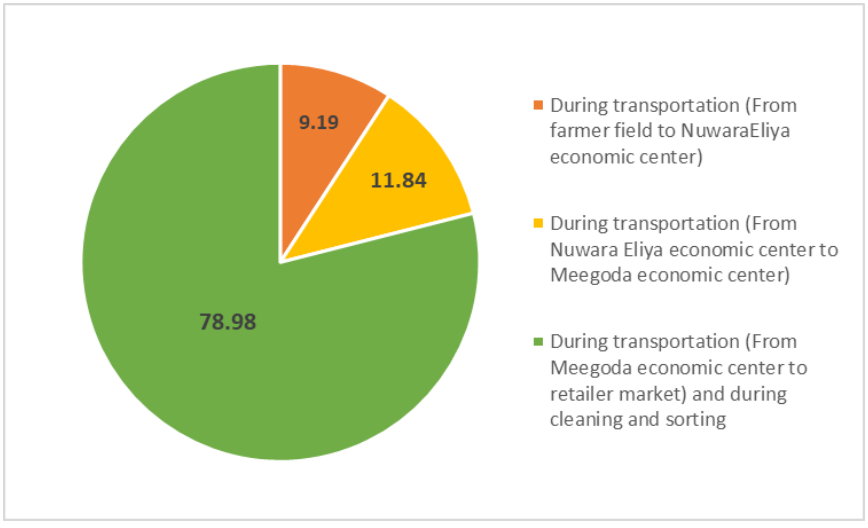

Fig. 3. Yield loss (%) occurred at each stage of the market chain as a proportion of the total yield loss

To minimize leek yield loss along the market chain, a robust plan should be developed, focusing on postharvest practices such as cleaning, sorting, transportation, and packing. According to reference [3], the best packaging for long-distance transportation of leeks is wooden boxes with dimensions of 75×45×30 cm and a filling height of 25 cm. Immediately after harvesting leeks should be cooled to reduce the field heat until it reaches a temperature around 0 °C. To do this hydrocooling and vacuum cooling are recommended for leeks. Meantime the relative humidity should be maintained around 95-100%. Under controlled environment conditions they can be stored for 4-5 months [6]. To overcome the yield loss caused by the use of poly-sacks for the transportation of leeks, replacing them with plastic crates also can be suggested. As further suggestions, establishing direct marketing channels between farmers/producers and supermarkets, bypassing collectors and wholesalers, setting up collection centers in major vegetable-producing areas for more efficient handling, packaging, and transportation, and integrating elements of a cold chain where appropriate to maintain quality can be mentioned [6]. Post-harvest losses are exacerbated by a lack of national standards, enforcement, ability, knowledge, and financial resources for product grading [5]. Therefore, government attention towards minimizing post-harvest losses of delicate crops is suggested.

IV. CONCLUSION

The recent study revealed that a considerable amount of leek yield is lost along the market chain, from the farmgate to the retailer markets in Nuwara Eliya and Colombo, totaling 40.09%. The study also indicated that this loss occurs in varying amounts at different stages of the market chain. The transportation, sorting, and cleaning processes at retailer markets were identified as the main contributors to the overall yield loss. Since these losses result in economic setbacks for everyone involved in the market chain, it is crucial to implement measures to minimize these losses. This may include implementing better transportation practices, as well as improving cleaning and sorting methods. It is particularly important to replace the conventional method of packaging leeks in 'mesh bags' with more suitable materials such as wooden boxes or plastic crates.

REFERENCES

[1] S. Ahamad, A. Kumar, C. Bihari, M. Kumar, G. K. Choupdar, M. Menaka, and V. Saurabh, "Advances production technology of leek," in *A Textbook on Advances in Production Technology of Temperate Vegetable Crops*, A. Kumar, S. Prakash, M. Wamiq, C. Bihari, and S. Ahamad, Eds. 2024, pp. 119-134.

[2] "Leeks," *Department of Agriculture*, 2024. [online] Available: https://doa.gov.lk/hordi-crop-leeks/. [Accessed: Aug. 30, 2024].

[3] R. M. N. A. Wijewardhane, T. M. R. Dissanayake, and W. M. C. B. Wasala, "Evaluation of the suitability of prototype wooden bulk packages for transportation of leeks (Allium porum) in Nuwara-Eliya to Dambulla vegetable supply chain in Sri Lanka," in *IV International Conference on Postharvest and Quality Management of Horticultural Products of Interest for Tropical Regions*, vol. 1278, Apr. 2017, pp. 111-116.

[4] H.M.V.T.Jayamal, H.K.S.P. Bandara, A.P.R.T. Pathirana, J.L.t. Madushanka, M.A.P. Madushani, D.T.A.I.T.Y. Dahanayaka, R.M.P.I. Rajapaksha, D.D.N. Vibodhani, R.M.S.M.B. Rathnayaka, "Postharvest losses of Cabbage along the market chain: A case study from Sri Lanka. 3rd International Research Conference Sri Lanka Technology Campus, 2003.

[5] P. Budhathoki, S. K. Pandey, and P. D. Magar, "Review on Post-Harvest Handling of Fruits and Vegetables to Minimize Loss," *Food and Agri Economics Review (FAER)*, vol. 2, no. 1, pp. 37-40, 2022.

[6] L. Rajapaksha, D. M. C. C. Gunathilake, S. M. Pathirana, and T. Fernando, "Reducing Post-Harvest Losses in Fruits and Vegetables for Ensuring Food Security—Case of Sri Lanka," *MOJ Food Process Technol.*, vol. 9, no. 1, pp. 7-16, 2021.

Advanced Yield Prediction in Rice Using UAV-Multispectral Imaging and Machine Learning Approaches in Sri Lanka

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***Abstract*— Rice is an essential food crop making a significant contribution towards food security worldwide, particularly in Asian countries like Sri Lanka where it is widely grown. Accurate prediction of rice yields is critical for enhancing resource management and minimizing agricultural risks. Traditional yield estimation methods are often labor-intensive and prone to inaccuracies. However, advancements in technology, particularly remote sensing, offer a promising alternative. The aim of this study is to predict paddy yields three commonly grown rice varieties in Sri Lanka (Bg 352, At 362, and Bg 360) non-destructively using machine learning and multispectral images. Information gathered from UAV-based multispectral images, such as the NDVI, LCI, and EVI vegetative indices, were used to build models for predicting outcomes. The performance of Random Forest (RF), Support Vector Regression (SVR), and Simple Linear Regression (LR) in predicting rice yield was compared. The results indicated that the Random Forest Model trained with NDVI data extracted from UAV images captured at booting stage, showed the higher precision with an R^2 of 0.81, 0.76, 0.69 for Bg 352, BG 360 and AT 362, respectively. These results could be effectively used to provide timely and accurate yield forecasts for farmers and help them to allocate resources better and improve productivity. Future research based on such precision agriculture technologies should explore additional environmental variables and expand model validation across different growing seasons and regions.**

Keywords—Machine Learning, Multispectral Imaging, NDVI, Precision Agriculture, Rice Yield Prediction

I. INTRODUCTION

Rice (*Oryza sativa* L) is a staple crop that plays a crucial role in ensuring global food security, particularly in countries like Sri Lanka [1]. Accurate yield prediction in rice crop is essential for optimizing resource allocation, improving farm management, and reducing agricultural risks [2]. Traditional methods of yield estimation, such as manual sampling and phenological observations, are often time-consuming, labor-intensive, and subject to human error. With recent advances in remote sensing and machine learning, it is now possible to develop models that can predict crop yields more accurately and efficiently [3].

In this study, we focused on commonly cultivated rice varieties in Sri Lanka. The objective was to develop non-destructive yield prediction models using multispectral imaging data and derived vegetation indices, integrated with machine learning algorithms [3] to develop prediction models for the yield response of rice varieties [4].

The application of multispectral images allows for the extraction of key vegetation indices such as the Normalized Difference Vegetation Index (NDVI), Leaf Chlorophyll Index (LCI) and the Enhanced Vegetation Index (EVI), which have been shown to correlate with crop growth and productivity. Machine learning models can handle complex data patterns and offer more accurate yield predictions compared to traditional methods [5].

This research explores the integration of multispectral imaging and machine learning techniques for build yield prediction models, contributing to precision agriculture practices that enhance productivity, profitability and resource use efficiency in rice cultivation.

II. METHODOLOGY

A. Study site & Experimental setup

The field experiments were conducted at the Rice Research and Development Institute, Batalagoda, Sri Lanka, situated in the Low Country Intermediate Zone (agro-ecological region IL1b), which is ideal for paddy cultivation. The experiment focused on three widely cultivated rice varieties in the 3½ months age class, namely, Bg 352, At 362, and Bg 360. The varieties were grown with standard agronomic practices, including fertilization and irrigation, consistent with the recommendations for the area. Each variety was planted in separate plots (6 m × 2.5 m; 15 m^2) to monitor the growth performance and yield under uniform conditions (Fig 1).

Fig 1. Study area

B. Data Collection

Multispectral images were captured at heading stages using a DJI Phantom 4 multispectral platform, manufactured by DJI (Shenzhen, China) at a height of 12.2 m (40 ft). The camera captured five bands: blue, green, red, red-edge, and near-infrared (NIR), which are essential for calculating vegetation indices.

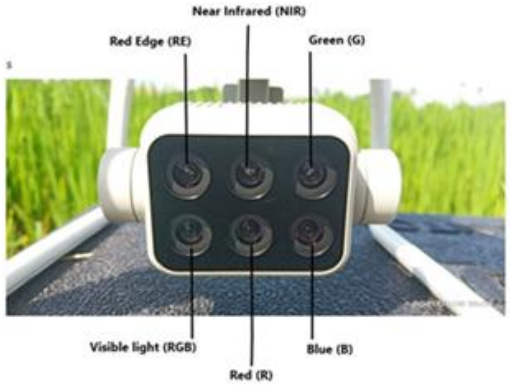

Fig 2. Multispectral sensor (P4M)

Ground-truth data for yield were collected at harvest by manually measuring grain yield from a designated sampling areas within each plot. Yield data were recorded in kilograms per hectare for each rice variety.

C. Vegetation Indices Calculation

The Vegetative Index values, including NDVI, GNDVI, NDRE, LCI, and RVI were calculated using the pix4dfield software (Pix4D S.A., Lausanne, Switzerland)

- NDVI = (NIR - Red) / (NIR + Red) [6]
- GNDVI = (NIR - Green) / (NIR + Green) [4]
- NDRE = (NIR - Red Edge) / (NIR + Red Edge) [6]
- LCI = (NIR - Red Edge) / (NIR + Red) [7]
- RVI = (NIR / Red) [3]

These indices were selected based on their proven correlation with crop biomass, and overall plant health, which are indicative of final grain yield.

D. Machine Learning Models for Yield Prediction

Three machine learning models, namely, Random Forest (RF), Support Vector Regression (SVR), and Simple Linear Regression (LR) were developed and evaluated for their ability to predict rice yield based on the vegetation indices.

The RF is a decision-tree-based ensemble method that aggregates multiple decision trees to improve predictive accuracy and mitigate overfitting. In this study, the RF model was trained using the calculated vegetation indices from the three rice varieties.

The SVR was used to map the relationship between vegetation indices and yield. This model is effective in handling nonlinear relationships by transforming the input data into higher-dimensional space using kernel functions. A radial basis function (RBF) kernel was selected for this study due to its ability to handle complex data patterns.

The LR served as a baseline model to evaluate the performance of more advanced methods. Relationship between the vegetation indices and yield was modeled using a simple linear regression equation.

E. Model Training and Validation

Vegetative Index (VIs) with the highest correlation with three yield parameters (number of panicles/m^2, 1000 grain weight (g), and yield/ha) were selected as the predictive variables. Subsequently, calibration models were established employing LR, SVR, and RF models. Each of the five VIs was individually assessed against all three yield parameters across the three varieties under consideration.

The models were evaluated based on the following performance metrics:

- Root Mean Square Error (RMSE): Measures the average magnitude of the error between predicted and actual yields.
- R-squared (R^2): Indicates the proportion of variance in the yield that is explained by the model.

The data were split into training and validation sets. Approximately 70% of the data was used for model training, while the remaining 30% was used for model validation.

Yield	Bg 352		Bg 360		At 362	
	R^2	RMSE	R^2	RMSE	R^2	RMSE
Simple Linear Regression						
Kg/ha	0.74	0.77	0.77	0.90	0.67	1.10
Random Forest Regression						
Kg/ha	0.81	0.65	0.76	0.87	0.69	1.05
Support Vector Regression						
Kg/ha	0.72	0.82	0.70	0.95	0.66	1.22

The results of the 5-fold cross-validation were summarized by averaging their key performance metrics (R^2, RMSE) to provide an overall measure of model performance for each regression technique (LR, SVR, and RF). The standard deviations of these metrics were also calculated to assess the variability and robustness of the models. This comparison highlighted the best-performing models and their consistency in the three predicting yield parameters stated above using NDVI. The models were further evaluated on the validation set to ensure they generalized well to unseen data, confirming their robustness and minimizing overfitting.

F. Statistical Analysis

A comparative analysis was conducted to evaluate the performance of each model in predicting yield. The performance of the RF, SVR, and LR models was statistically compared using RMSE and R^2 values. Further, sensitivity analysis was performed to identify the most influential vegetation indices contributing to yield prediction accuracy.

III. RESULTS AND DISCUSSION

A. Relationships Between Three yield Parameter and Vegetation Indices

Results of the correlation analysis indicated a good correlation between the five Vegetative Indices (VIs) and the three yield parameters. The highest correlation coefficients were observed between the NDVI and number of panicles/m^2, 1000 grain weight (g) and yield/ha. The correlation coeeificents between NDVI and the three yield parameters for Bg 352 were 0.825, 0.623 and 0.785, for Bg 360 were 0.775, 0.664 and 0.790, and for At 362 were 0.632, 0.594, and 0.693, respectively. This highlighted the significance of NDVI, which was selected as the most influential vegetation index contributing to yield prediction accuracy in paddy.

B. Yield Prediction Performance

The three machine learning models RF, SVR, and LR were evaluated for their ability to predict the yield of the three rice varieties based on NDVI. The performance of each model is summarized in Table 1.

TABLE I. SUMMARIZATION FOR MODELS ACCURACY RESULTS

Across all models and varieties, R^2 values provided insights into the proportion of variance in the dependent variable that is predictable from the independent variable (NDVI), while RMSE values quantify the average magnitude of the residuals or prediction errors. These metrics serve as indicators of model accuracy and goodness of fit. The comparison of R^2 and RMSE values facilitates the assessment of model effectiveness in predicting the target variables for each variety, thereby aiding in the selection of the most suitable predictive model for agricultural applications.

The RF model demonstrated the highest prediction accuracy, with the highest R^2 values and the lowest Root Mean Square Errors (RMSE) (Table 1). This indicates that the RF was able to capture complex relationships between vegetation indices and yield with high precision, making it the best performing model in this study.

Thus, RF model was selected as the best fitted model for predicting yield/ha using NDVI value having showed lower RMSE and higher R^2 (Table1). These findings highlight the effectiveness of the Random Forest Regression model in accurately predicting yield for three rice varieties, as evidenced by both higher R^2 values and lower RMSE values.

C. Model Performance by Rice Variety

The models performed differently across the three rice varieties, with only slight variations in prediction accuracy. It showed better predictability of yields of varieties Bg 352 and Bg 360 compared to that of At 362. The R^2 values for Bg 352 and Bg 360 were marginally higher (0.81 and 0.76, respectively), while At 362 had a lower R^2 value of 0.69. This difference could be attributed to spatial variability between the rice varieties.

D. Implications for Precision Agriculture

The successful implementation of multispectral imaging and machine learning for yield prediction holds significant potential for precision agriculture, particularly in paddy cultivation. By leveraging vegetation indices and advanced machine learning models like RF and SVR, farmers and agricultural practitioners can gain early insights into expected paddy yields, allowing for more informed decision-making regarding resource allocation, irrigation scheduling, and fertilization management. [8].

The RF Model offers the best balance of accuracy and interpretability, making it a valuable tool for on-farm yield prediction. Its ability to handle complex interactions between input variables suggests its robustness across different environmental conditions [3].

The findings of this study demonstrate the feasibility of integrating multispectral imaging and machine learning for yield prediction in paddy cultivation, providing a pathway for enhancing productivity and sustainability in paddy farming systems [7].

E. Limitations and Future Research

Despite the success of the models, several limitations should be acknowledged. The study relied on a limited number of vegetation indices and did not account for other environmental variables such as soil moisture and nutrient levels, which could further enhance the prediction models. Future research should explore the integration of additional multispectral indices and environmental factors to improve prediction accuracy.

Furthermore, extending the study across multiple growing seasons and different geographic locations would validate the robustness of the models under varying climatic and soil conditions. The potential for incorporating other advanced machine learning techniques, such as deep learning models, should also be explored for even more accurate yield forecasting.

IV. CONCLUSION

The methods developed in this study integrated UAV-based multispectral imagery with machine learning models to predict rice yield accurately and efficiently. This approach has significant potential to improve the decision-making processes in paddy cultivation by providing timely and precise assessments of crop conditions, enabling better management of resources to optimize yield. Future studies should build on the outcome this research by exploring additional VIs and testing the models under different environmental conditions and paddy varieties.

REFERENCES

[1] R. Gebbers and V. I. Adamchuk, “Precision agriculture and food security,”, 2010. doi: 10.1126/science.1183899. I. S. Jacobs and C. P. Bean, “Fine particles, thin films and exchange anisotropy,” in Magnetism, vol. III, G. T. Rado and H. Suhl, Eds. New York: Academic, 1963, pp. 271–350.

[2] J. V. Stafford, “Implementing precision agriculture in the 21st century,” Journal of Agricultural and Engineering Research, vol. 76, no. 3, pp. 267–275, 2000, doi: 10.1006/jaer.2000.0577. R. Nicole, “Title of paper with only first word capitalized,” J. Name Stand. Abbrev., in press.

[3] F. J. Pierce’ and P. Nowak, “ASPECTS OF PRECISION AGRICULTURE,” 1999.M. Young, The Technical Writer’s Handbook. Mill Valley, CA: University Science, 1989.

[4] N. Zhang, M. Wang, and N. Wang, “Precision agriculture*/ a worldwide overview.” [Online]. Available:

[5] “Identification of paddy vegetative phase ndvi changes - Google Scholar”.

[6] Y. Zhang et al., “Study on the Estimation of Leaf Area Index in Rice Based on UAV RGB and Multispectral Data,” Remote Sens (Basel), vol. 16, no. 16, Aug. 2024, doi: 10.3390/rs16163049.

[7] D. Goigochea-Pinchi et al., “Yield Prediction Models for Rice Varieties Using UAV Multispectral Imagery in the Amazon Lowlands of Peru,” AgriEngineering, vol. 6, no. 3, pp. 2955–2969, Aug. 2024, doi: 10.3390/agriengineering6030170.

[8] 2015 IEEE 3rd International Conference Actual Problems of Unmanned Air Vehicles Developments (APUAVD): proceedings: October 13-15, 2015, Kyiv, Ukraine. IEEE, 2015.

Development of Chai Tea-Flavored In-bottle Sterilized Milk

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***Abstract*— Chai tea, originating from India, is a daily life and culture, enjoyed by 80 million people daily. This spiced, warming tea has been integral to Indian culture for centuries, becoming widely popular by the mid-1900s. (George, 2023) This study focuses on the development of chai tea- flavored in bottle sterilized milk, combining traditional flavors with modern convenience. In-bottle sterilization is a process involving heat treatment of the milk within its packaging, ensuring the product's microbial safety and extended shelf life. The study involved formulating various blends of spices like cinnamon, cardamom, ginger and hot water-soluble instant tea into different concentrations to achieve an optimal balance of flavors. From the preliminary trials, spicy mixture was selected for better formulation. Four types of treatment were prepared, and all treatments contain a 0.7 % chai tea spicy mixture but contain different level of cinnamon, cardamom, ginger and hot water-soluble instant tea. Sensory analysis was conducted by untrained 40 panelists using 5-point hedonic scale (1=extremely dislike, 5=extremely like) The obtained data was analyzed based on sensory results 0.08 % cinnamon, 0.20 % cardamom, 0.25 % ginger and 0.17 % hot water-soluble instant tea contain sample was selected. The selected sample was evaluating pH, titratable acidity and microbial properties during four weeks of storage. Also, the selected sample was evaluated its proximate parameters and cost of production aim to deliver a novel and flavorful milk beverage to the market.**

Keywords—chai tea, flavored milk, in-bottle sterilization, sensory evaluation

I. INTRODUCTION

In recent years, the global beverage industry has experienced a notable shift towards products that blend traditional flavors with modern convenience. This trend is driven by consumer demand for innovative, ready-to-drink (RTD) beverages. That offers both nutritional value and Chai tea- flavored in-bottle sterilized milk stands out as a compelling new product that gives the rich, aromatic spices of chai tea with the creamy texture of milk. Integrating chai tea flavors into milk represents a promising opportunity to create a novel product that aligns with current market trends. The development of chai tea- flavored in-bottle sterilized milk represents a novel addition to the rapidly expanding category of RTD beverages that offer a harmonious blend of tradition and modernity.

Chai tea, with its origins deeply rooted in Indian culture that spiced tea known for its complex and capitative flavor profile. Typically, chai tea includes a blend of spices such as cardamom, cinnamon and ginger which contribute to its distinctive taste and potential health benefits. These benefits include antioxidant properties and anti-inflammatory effects, attributed to the bioactive compound present in spices. Milk, on the other hand is a staple in many diets around the world. Its nutritional content includes proteins, vitamins and minerals. Combining these two elements into a single beverage offers a dual advantage.

The modern consumer's lifestyle increasingly favors convenience, making ready-to-drink beverages an essential segment of the beverage market. Chai tea flavored in-bottle sterilized milk aligns with this trend, offering a ready -to-consume a product that preserves the traditional essence of chai tea. In-bottle sterilization is a process involves heat treatment of the milk within its packaging, ensuring that the product ensures microbial safety, stability and extended shelf life. (FSSA, 2013)

This research is conducted to develop chai tea flavored in-bottle sterilized milk with higher sensory attributes, good solubility and low cost of production. The development of chai tea- flavored in bottle sterilized milk represents a unique intersection of tradition and innovation. By combining the nutritional benefits of milk with the exotic flavors of chai tea, this product has the potential to resonate with consumers seeking convenient, flavorful and nutritious beverage options.

II. METHODOLOGY

A. Location of the Research

The experiment was carried out at the Chello Dairy Products (Pvt) LTD, Godakawela, Rathnapura

B. Selection Of Raw Materials

Fresh milk for the study was obtained from the milk reception at Chello Dairy Products (Pvt) LTD, Godakawela, Rathnapura. Temperature, pH and Fat content (Gerber, 1892) were measured to check the initial quality of raw milk obtained. Also, other milk screening tests were done to check the initial quality of milk.

Ginger, cinnamon, cardamom and other ingredients were obtained from the local market.

C. Preparation Of Chai Tea Spicy Mixture

Ginger powder

Ginger rhizomes were washed in running tap water. Peeled and cut into 2-5 mm slices. Sliced ginger was dehydrated at 50 ˚C for 7 hours. Dehydrated ginger slices were ground using an electrical grinder. The prepared ginger powder was packed in low dense airtight polythene and sealed.

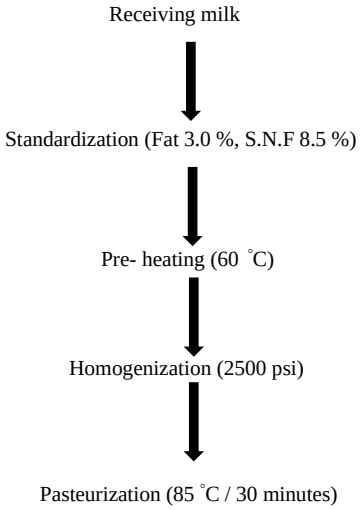
Cinnamon powder

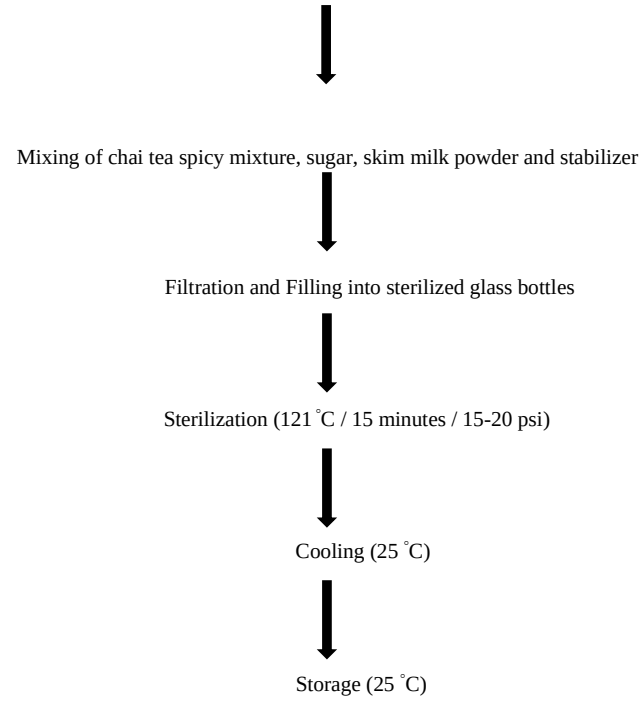
Cinnamon sticks were dehydrated at 60 ˚C for about 4 hours using a drying oven. Dehydrated cinnamon was ground using an electrical grinder Prepared cinnamon powder was packed in low dense airtight polythene and sealed.

Cardamom powder

The seeds were roasted using a dry pan. The seeds were removed from cardamom pods. Next, the seeds were ground using an electrical grinder until they formed a fine powder. The cardamom powder was then stored in an airtight container to preserve its freshness and aroma.

D. Development Of Chai Tea Flavored In Bottle Sterilized Milk





[9] Flow chart of chai-tea flavored in-bottle sterilized milk

E. Experimental design

TABLE 1. EXPERIMENTAL DESIGN FOR THE CHAI TEA SPICY MIXTURE (PER 100 ML OF MILK)

Ingredients	**Experimental group**			
	T 1	**T 2**	**T 3**	**T 4**
Cinnamon powder	0.05 %	0.07 %	0.06 %	0.08 %
Cardamom powder	0.10 %	0.08 %	0.14 %	0.20 %
Ginger powder	0.30 %	0.35 %	0.40 %	0.25 %
Hot water-soluble instant tea	0.25 %	0.20 %	0.10 %	0.17 %

F. Sensory Evaluation

Sensory evaluation was conducted at Chello Dairy Products (Pvt) Ltd, Godakawela, Rathnapura, with 40 untrained panelists. It was done for color, flavor, appearance, consistency, odor and overall acceptability using 5- a point hedonic scale.

G. Physico-Chemical Analysis

- The pH and titratable acidity of the samples were measured during storage period according to the (AOAC,2000) procedure.
- Total solid content was determined using (AOAC,2016) procedure.
- Ash content was determined using a muffle furnace according to the (AOAC, 2016) procedure.

- Fat content was determined using the Gerber method according to the (AOAC, 2016) procedure.
- Protein content was determined by the Kjeldahl method according to the (AOAC, 2016) method.
- Brix value was measured using a refractometer and turbidity value was measured using a turbidity meter.
- Antioxidant content was analyzed by the DPPH method by Palthuur et al., (2014)

H. Microbial Analysis

Total plate count, yeast and mold count and coliform count were analyzed using methods employed in the manual of microbial testing FSSAI (2012)

I Statistical Analysis

The sensory data was analyzed by using the Friedman non-parametric test in MINITAB 17.1 with a 95 % confidence interval. The pH value of the sample was analyzed using One-way ANOVA in a completely randomized design (CRD) using MINITAB 17.1 statistical software.

J. Cost Analysis

The production cost for a 200 ml bottled sterilized milk product was calculated.

III. RESULTS AND DISCUSSION

A. Preliminary Trials

Preliminary trials were conducted to optimize the level of ingredients

TABLE 2. PRELIMINARY TRIALS FOR SELECTION OF INGREDIENTS

Ingredients	**Level selected**
Sugar	8 %
Ginger powder	0.25- 0.40 %
Cinnamon powder	0.05-0.08 %
Cardamom powder	0.10- 0.20 %
Hot water-soluble instant tea	0.1 – 0.25 %
Carrageenan	0.015 %
Tri sodium phosphate	0.09 %

B. Results Of Sensory Evaluation

TABLE 3. RESULTS OF SENSORY EVALUATION

Sensory Attributes	**T 1**	**T 2**	**T 3**	**T 4**	**P value**
Color	4.300 ±0.14^{a}	4.075 ±0.17^{a}	3.775 ± 0.14^{b}	4.125 ±0.15^{a}	0.007
Flavor	4.075 ±0.17^{a}	3.725 ±0.17^{b}	3.775 ± 0.13^{b}	4.475 ± 0.11^{c}	0.000
Appearance	4.050 ±0.13^{a}	3.750 ±0.18^{b}	3.950 ± 0.14^{a}	4.450 ± 0.12^{c}	0.004
Consistency	3.950 ±0.15^{a}	3.850 ±0.17^{a}	3.650 ± 0.14^{a}	4.475 ±0.11^{b}	0.000
Odor	3.975 ±0.15	3.750 ±0.17	3.775 ± 0.17	4.200± 0.17	0.056
Overall acceptability	4.125 ±0.15^{a}	3.800 ±0.17^{b}	3.825 ± 0.15^{b}	4.500 ± 0.13^{c}	0.000

$^{a\text{-}c}$The different letters mentioned in each value of the identical row are significantly difference. ($p < 0.05$)

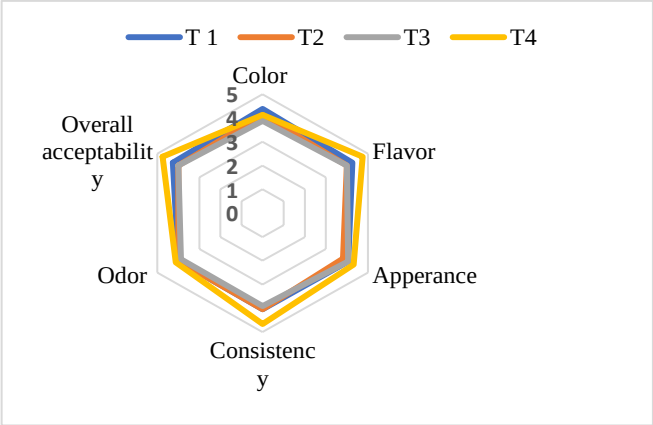


fig 2. Sensory evaluation radar chart of chai tea flavored in-bottle sterilized milk

C. pH

The pH was analyzed in triplicate, showing a slight decrease in pH throughout the storage period.

Table 4. Changes of pH values (MEAN ± STANDARD ERROR OF MEAN in chai tea flavored in-bottle sterilized milk

	Week 1	**Week 2**	**Week 3**	**Week 4**
pH	6.34 ±0.00^{a}	6.31±0.00^{ab}	6.27±0.02^{b}	6.26±0.01^{b}

[a-b]*The different letters mentioned in each value of the identical row are significantly difference. (p < 0.05)*

D. Titratable Acidity

TABLE 5. CHANGES OF TITRATABLE ACIDITY VALUES (MEAN ± STANDARD ERROR OF MEAN IN CHAI TEA FLAVORED IN-BOTTLE STERILIZED MILK

	Week 1	**Week 2**	**Week 3**	**Week 4**
Titratable acidity	0.05±0.00[c]	0.05±0.00[bc]	0.05±0.00[b]	0.06±0.00[a]

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

E. Other physicochemical parameters

TABLE 6. PHYSICOCHEMICAL PARAMETERS OF THE FINAL PRODUCT

Parameter	*Value*
Protein content (%)	*3.3*
Fat content (%)	*0.52 ±0.01*
Ash content (%)	*0.07±0.00*
Total solid content (%)	*22.02±0.28*
Carbohydrate content	*17.95*
Total soluble solid content	*20°*
Sedimentation (FAU)	*412*
Antioxidant content (%)	*63.45*

F. Microbial analysis

TABLE 7. CHANGES IN MICROBIAL PROPERTIES DURING FOUR WEEKS

Microbial parameter	**Week**			
	Week 1	**Week 2**	**Week 3**	**Week 4**
Total plate count	Nil	Nil	Nil	Nil
Coliform count	Nil	Nil	Nil	Nil
Yeast & mold count	Nil	Nil	Nil	Nil

Over a four weeks period the microbial analysis of the samples showed no detectable microbial counts. This absence of microbial presences indicates the successful implementation of strict hygiene practices during production, packaging and sealing process.

G. Cost analysis

The cost of newly developed chai tea-flavored in-bottle sterilized milk (200 ml) was Rs. 253.76.

CONCLUSION

The study investigated the impact of adding different concentrations of cinnamon powder, ginger powder, cardamom powder and hot water-soluble instant tea.

The sensory evaluation revealed that the 0.08 % cinnamon powder, 0.20 % cardamom powder, 0.25 % ginger powder and 0.17 % hot water-soluble instant tea contain sample had the highest overall acceptability score. There were significant differences in color, flavor, appearance and overall acceptability among the samples. However, there was no significant difference in odor. During the four weeks of the storage pH was decreased and titratable acidity was increased. Also, during the four weeks of storage period total plate count, coliform count, yeast and mold count were absent. This product contains no artificial flavors and colorants, offering a natural, healthier choice for a balanced life style.

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REFERENCES

[1] Guneser, O., Hosoglu, M.I., Guneser, B.A. and Yuceer, Y.K., 2019. Engineering of milk-based beverages: current status, developments, and consumer trends. In Milk-based beverages (pp. 1-37). Woodhead Publishing.

[2] Hinsdale, S., Pace, J., Anderson, E. and Favoreto, S., 2018. Chai Tea Promotes Ampicillin Susceptibility in MRSA. The FASEB Journal, 32, pp.809-1.

[3] Gaur, G.K., Rani, R., Dharaiya, C.N. and Solanki, K., 2019. Development of herbal milk using tulsi juice, ginger juice and turmeric powder. International Journal of Chemical Studies, 7(2), pp.1150-1157.

[4] Morales, F.J., Romero, C. and Jiménez-Pérez, S., 2000. Characterization of industrial processed milk by analysis of heat-induced changes. International journal of food science & technology, 35(2), pp.193-200.
[5] Contarini, G., Povolo, M., Leardi, R. and Toppino, P.M., 1997. Influence of heat treatment on the volatile compounds of milk. Journal of Agricultural and Food Chemistry, 45(8), pp.3171-3177.
[6] Sunarharum, W.B., Ali, D.Y., Hasna, T., Pradichaputri, A., Sabatudung, A.N., Nurizza, N.E., Farras, M.I.S. and Kartika, A.A., 2022. The potential of spiced tea for health. Advances in Food Science, Sustainable Agriculture and Agroindustrial Engineering (AFSSAAE), 5(2), pp.193-200.
[7] Tiwari, P.K. and Asgar, S., 2017. Diversification in flavoured milk: A review. International Journal of Clinical and Biomedical Research, pp.15-20.
[8] De Pelsmaeker, S., Schouteten, J. and Gellynck, X., 2013. The consumption of flavored milk among a children population. The influence of beliefs and the association of brands with emotions. Appetite, 71,pp.279-286
[9] George, A.S., 2023. The Scale and Scope of India's Vital Chai Industry. Partners Universal International Innovation Journal, 1(6), pp.72-84
[10] Palthur, S., Anuradha, C.M. and Devanna, N., 2014. Development and evaluation of ginger flavored herbal milk. Res J Agric Env Sci, 1, pp.54-59.

Enhancing the Sensory Attributes of Yoghurt Using Fortification of Ginger (*Zingiber officinale* Roscoe) Extract

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***Abstract*— This study aimed to develop a yogurt by fortifying it with ginger extracts and evaluating the sensorial quality of the yogurt at 1%, 2%, and 3% fortification levels. The ginger extracts were initially obtained using the Soxhlet extraction and maceration methods. Following this, the extraction method that produced the highest total phenolic content was selected to fortify yoghurt, and sensory analysis was conducted to evaluate the attributes, including color, aroma, texture, flavor, mouthfeel, aftertaste, and overall acceptability. According to the total phenolic assay results, the Soxhlet extracted ginger extract, which exhibited 110.19±0.68 mgGAE/ml of total phenolic content, was selected to prepare the fortified yoghurt. According to the results, 1% ginger extract fortified yogurt showed significantly higher acceptance for color, aroma, texture, flavor, mouthfeel, aftertaste, and overall acceptability than the control group. On the other hand, 2% ginger extract fortified yogurt exhibited the second-highest improved sensory attributes, but it was not significant compared to the control group. However, 3% of ginger extract fortified yogurt had the lowest acceptance for all the evaluated sensory attributes. These findings indicate the potential for ginger extract fortification to improve yogurt quality, providing the opportunity to develop appealing and functional yogurt products.**

Keywords*— *Fortification, Yoghurt, Zingiber officinale Roscoe, Sensory, Soxhlet extraction

I. INTRODUCTION

Yogurt is a milk product frequently used as a functional food because of its complete sensory and nutritional qualities and its positive impact on human health [1]. As people move towards functional food products, yogurt has become an essential dairy product worldwide. It has been recognized as a health-promoting food, claiming it can help prevent disease beyond its fundamental nutritional role [2]. As a novel trend, yogurts are now fortified with different plant-based materials such as herbs, spices, fruits, and vegetables to enhance yogurts' functional properties. Fortification of yogurt with plant materials improves the nutritional properties, therapeutic properties, and sensory attributes[3].

Ginger (*Zingiber officinale* Roscoe) is one of the oldest medicinal plants used for traditional medicines in many countries, and this valuable plant has proven its medicinal properties many times. The health benefits of ginger are mostly due to the presence of important phenolic compounds such as 6-gingerol, 6-shogaol, 6-azashogaol, 6-azagingerol, isoxazoline derivative, zingerone, and paradols [4]. These phytochemicals exhibit excellent anti-inflammatory, anti-cancer, antipyretic, antioxidant, cardiotonic, and hypotensive properties. Furthermore, ginger contains high amounts of vitamins, amino acids, and phenolic compounds. However, ginger is important not only for medical purposes but also for culinary purposes as a flavoring and preservative agent most of the time.

This study evaluated the possibility of improving the sensorial quality of set yogurts by incorporating ginger extract.

II. METHODOLOGY

A. Preparation of plant materials and extracts

Ginger (*Zingiber officinale* Roscoe) rhizomes were obtained from the Kaluaggala, Sri Lanka cultivation site. Plant materials were authenticated by the National Herbarium at Peradeniya. After that, rhizomes were washed and cleaned. Then, plant materials were oven-dried at 50 °C overnight. A mass of 5 g of oven-dried *Zingiber officinale* rhizomes were Soxhlet extracted and macerated according to the method of Adaramola et al. [5]. The extracts were then concentrated using a rotary evaporator until very thick solutions were obtained and stored at -24 °C in the freezer.

B. Total phenolic analysis

In order to determine the best extraction method, the total phenolic content of the obtained extracts was assessed using the Folin-Ciocalteu method in accordance with the procedure described by Nirmala et al. [6]. 5 mL of 10% Folin-Ciocalteu reagent and 4 mL of 7% Na_2CO_3 solution were added for each 1mL of ginger extracts. The resulting mixture was then well shaken and incubated for 30 minutes in a water bath at 40 °C.

The mixture's absorbance was then measured at 760 nm compared to a blank.

C. Preparing Ginger Extract Fortified Yoghurt

Standardized non-adulterated raw milk was purchased from the local market. Then, sugar, milk solids, nonfat, and gelatin were added to the mixture. After that, different concentrations (1, 2, and 3%) of ginger extracts were added to the yoghurt mixture, while the control sample was prepared without adding ginger extracts. Then pasteurized at 72 °C for 15 seconds and cooled to 42-43 °C. Yoghurts were then inoculated with a starter culture. Inoculated yoghurt mixture was then incubated at 45 °C until the pH reached 4.6.

D. Sensory Analysis

Sensory evaluation for ginger extract fortified yogurt and plain yogurt was done in the food processing laboratory at the Faculty of Technology, University of Sri Jayewardenepura, using 30 semi-trained panelists, and a 9-point hedonic scale was used for the sensory evaluation of color, aroma, texture, flavor, mouthfeel, aftertaste, and overall acceptability of fortified yoghurts.

E. Statistical Analysis

The obtained data were analyzed using IBM SPSS statistic 21 software. Mean values were calculated in each case, and multiple comparisons were conducted using Tukey's HSD test. Throughout the analysis, differences were considered significant at $P < 0.05$.

III. RESULTS AND DISCUSSION

A. Total Phenolic Analysis

The Folin-Ciocalteu method is a quantitative analysis method to determine the total phenolic content. In this work, this assay was performed to identify the highest total phenolic yielded extraction method between Soxhlet extraction and maceration. During this experiment, Soxhlet yielded significantly the highest total phenolic content of 110.19±0.68 mgGAE/mL, whereas macerated ginger extract exhibited 86.04±0.16 mgGAE/mL. These results imply that Soxhlet extraction is a more effective way to extract phenolic chemicals, presumably because the solvent is continuously circulated at a higher temperature, which enhances contact and solubilizes the compounds from the plant matrix [5]. Therefore, soxhlet extracted ginger extract was used to prepare the yoghurt.

Table 1. Total phenolic content of two extraction methods

Extract method	***Total phenolic content* (mgGAE/mL)**
Soxhlet extraction	110.19±0.68[a]
Maceration	86.04±0.16[b]

Each data point represents the mean ± SD (n = 3), and different letters (a and b) indicate a significant difference in the same column. GAE=Gallic acid equivalents

B. Sensory Analysis

The summary of the obtained sensory analysis is represented in Fig 1. According to the results, 1% ginger extract fortified yoghurt obtained 7.41, 7.24, 7.32, 7.94, 7.68, 7.59, and 7.91 for color, aroma, texture, flavor, mouthfeel, aftertaste, and overall acceptability, respectively. Further, 2% ginger extract fortified yoghurt obtained 7.32, 7.38, 7.35, 6.94, 6.74, 6.53, and 7.21 for color, aroma, texture, flavor, mouthfeel, aftertaste, and overall acceptability, respectively. 3% ginger extract fortified yoghurt exhibited 6.88, 6.41, 6.03, 6.38, 6.21, 5.74, and 6.03 for color, aroma, texture, flavor, mouthfeel, aftertaste, and overall acceptability, respectively. Finally, the control sample obtained 7.03, 7.06, 7.15, 6.91, 6.91, 6.38, and 7.12 for color, aroma, texture, flavor, mouthfeel, aftertaste, and overall acceptability, respectively

According to the sensory evaluation, 1% fortified yoghurt obtained the highest score for color, flavor, mouthfeel, aftertaste, and overall acceptability. Among these sensory attributes, flavor, mouthfeel, aftertaste, and overall acceptability showed a significant difference ($P<0.05$) compared to the control group. However, 2% fortified yoghurt obtained the highest scores for aroma and texture. However, 2% of ginger extract fortified yogurt exhibited scores slightly lower than 1% of ginger extract fortified yogurt in terms of color, flavor, mouthfeel, aftertaste, and overall acceptability. Moreover, the obtained values were not significantly higher than the control group ($P>0.05$). The 3% ginger extract fortified yoghurt exhibited the lowest acceptance for all the sensory attributes. However, it was not significantly ($P>0.05$) lower than the control group except for texture and overall acceptability.

These results showed that lower concentrations of ginger extract (1% and 2%) improved the sensory attributes of the yogurt, notably in terms of flavor and overall acceptability. Across all sensory characteristics, the 1% fortification level was the most preferred. Conversely, the 3% fortified yogurt obtained lower scores, demonstrating that a larger concentration of ginger extract may have a negative impact on the sensory experience. These findings emphasize the need to carefully adjust the concentration of ginger extract in ginger-spiced yogurt to achieve the appropriate sensory character.

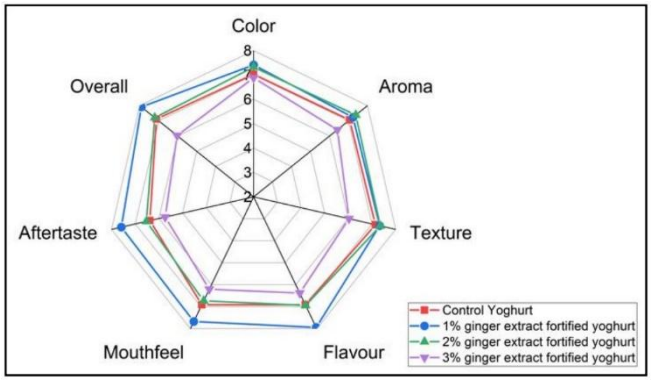

Fig 1.Spider diagram of sensory evaluation of ginger extract fortified yogurts

IV. CONCLUSION

It can be concluded that the Soxhlet extraction of dried ginger powder provides higher total phenolic content than the maceration, which could be beneficial in terms of developing phenol-enriched yogurt. Further, ginger extract can significantly influence the quality of yogurt by altering its color, aroma, texture, flavor, mouthfeel, and aftertaste. Moreover, the fortification level also plays a crucial role in changing the sensorial quality of the yogurt. According to this experiment, the most suitable and acceptable fortification level of ginger extracts is 1%.

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REFERENCES

[1] Sodini, I., et al., Physical properties of yogurt fortified with various commercial whey protein concentrates. 2005. 85(5): p. 853-859.
[2] Shori, A.B.J.B. and A. Biotechnology, The potential applications of probiotics on dairy and non-dairy foods focusing on viability during storage. 2015. 4(4): p. 423-431.
[3] Ahmad, I., et al., Fortification of yogurt with bioactive functional foods and ingredients and associated challenges - A review. Trends in Food Science & Technology, 2022. 129: p. 558-580.
[4] Kumar, N.V., et al., Synthesis and quorum sensing inhibitory activity of key phenolic compounds of ginger and their derivatives. 2014. 159: p. 451-457.
[5] Adaramola, B. and A.J.C.I. Onigbinde, Influence of extraction technique on the mineral content and antioxidant capacity of edible oil extracted from ginger rhizome. 2017. 3(1): p. 1-7.
[6] Phuyal, N., et al., Total phenolic, flavonoid contents, and antioxidant activities of fruit, seed, and bark extracts of Zanthoxylum armatum DC. 2020. 2020.
[7] Menon, A.N., et al., Effects of Processing on the Flavor Compounds of Indian Fresh Ginger (*Zingiber Officinale* Rose.). Journal of Essential Oil Research, 2007. 19(2): p. 105-109.

Humanities and Social Sciences, Culture and Education

Balancing Work and Life: Exploring the Right to Disconnect in Sri Lanka through Comparative Analysis with France and Australia.

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***Abstract*— This research explores the right to disconnect in Sri Lanka through a comparative analysis with France and Australia. An increasing number of employees are working past usual business hours without legal cover as remote work grows more common, especially in industries like IT and apparel. The lack of regulations regarding the right to disconnect in Sri Lankan labor laws results in the infringement of employees' rights to equality and leisure. The main objectives of this study are to find the current legal framework in Sri Lanka, analyze measures in France and Australia that have strong legal coverage for work outside of working hours, and suggest recommendations for Sri Lanka regarding the right to disconnect. This study examines the legal frameworks of the two countries regarding the right to disconnect using comparative and doctrinal methodologies. Australia introduces legislation allowing employees to decline work contacts outside of business hours from 26 August 2024. France requires large enterprises to negotiate work-life balance policies. On the other hand, because Sri Lanka lacks this legislation, employees continue to be exploited and have no legal redress. The study concludes that to improve work-life balance and comply with international standards, Sri Lanka has to enact specific laws establishing and safeguarding the right to disconnect like France and Australia where these laws are practiced properly. It is recommended to include legal provisions, establish enforcement mechanisms, enact legislative changes that clearly define the right to disconnect, fines for non-compliance, and methods for staff members to report violations. Protecting workers' rights and bringing Sri Lanka into compliance with international standards, would encourage a better work-life balance throughout Sri Lanka.**

Keywords— Right to Disconnect, Work-Life Balance, Comparative Analysis, Labor Laws, Remote Work Regulations

I. INTRODUCTION

With the rapid increase of private sector organizations worldwide, organizations encourage employees to work from home. Therefore, more employees start working from home on devices issued by the organizations. Also, even if it is not work from home some employees have to work out of hours due to the nature of their work. So, the right to disconnect is a system that works against this. It means the employee has a right to disconnect outside of normal working hours. This is also happening in Sri Lanka's IT and apparel sectors. Now it is moving to government organizations also. If the employee has not signed up with the organization for on-call or out-of-hours work, this is the right violation of the employee. So, the employee can take action against this situation. However, the Sri Lankan legal system has no labor laws regarding the above violation. However foreign jurisdictions like France and Australia have legal provisions for this violation. This study aims to analyze the above two foreign legal systems and recommend improvements in the Sri Lankan legal system.

II METHODOLOGY

The study used comparative and doctrinal methodologies. Doctrinal research methodology refers to research articles, websites, magazines, and legal books. For the Comparative research methodology, the Sri Lankan legal system is compared with the legal systems of France and Australia. Finally, based on the analysis make recommendations for Sri Lanka.

III . RESEARCH OBJECTIVES

1. To identify the prevailing legal framework in Sri Lanka for violation right to disconnect.
2. To analyze the legal coverage to protect the right to disconnect in France and Australia.
3. To compare the three legal frameworks and make recommendations for Sri Lanka.

IV. RESEARCH PROBLEM

In Sri Lanka, even though most employees work out of working hours at home without payments there is no legal coverage for them.

V. ANALYSIS AND DISCUSSION

A. Right to Disconnect in Sri Lanka.

In Sri Lanka, there are government employees and private sector employees. Most of the employees work over working hours without any payment (Wanigasinghe,2019). From these human rights of the employees are violated. Example the Right to Leisure. Indeed, the Sri Lankan constitution Article 12(1) also discussed the right to equality. The overtime work without payment is done by management assistants and clerks, who are middle-level employees. So, the managerial persons get the work from these middle-level employees without any payment. This violates the right to equality under Article 12(1) of the Sri Lankan Constitution. Further in Sri Lankan labor laws, there is no provision for the right to disconnect. So, it is a loophole in the Sri Lankan legal framework.

B. Right to Disconnect in France.

The French legal system has recognized the right to disconnect as an important idea for preserving work-life balance. This privilege, which the French Supreme Court first recognized in 2004, was fully incorporated into the French Labour Code by the Law on August 8, 2016, and became enforceable on January 1st, 2017 (CMS Legal, 2018). The right to disconnect, though not precisely defined by law, often refers to an employee's ability to turn off work-related digital tools like email and smartphones during non-working hours, such as vacation and leisure time. This right, which aims to protect their time and health, applies to all employees, regardless of their position or responsibilities.

Companies with at least 50 employees are required to execute this right; these businesses are also subject to yearly negotiations on professional equality and workplace quality of life. These businesses must set policies that permit workers to use their right to unplug and put in place safeguards that guarantee observance of required breaks, vacation time, and personal time. Businesses that use day-off agreements, in which working time is determined by the number of days worked rather than the number of hours worked, are likewise subject to the law (Loic and Pons, 2022). Smaller businesses, not expressly required by this legislation, are encouraged to set explicit policies about the right to disconnect. By taking this precaution, employers can avoid any rights violations that result in claims against them under their duty of care, particularly those related to rest and health (CMS Legal, 2018).

A key component of the right to disconnect successful implementation is negotiation. Employers are urged to consult with trade union representatives to ascertain the practical implementation of this right. If talks break down, the employer is required, after consulting with employee representatives, to create an internal policy that encourages managers to utilize digital tools properly. Such a policy has the same legal standing as a unilateral pledge and to be enforced, it must adhere to certain procedural criteria, such as consulting the Works Council and the Health and Safety Committee before being submitted to the Labour Inspectorate (Secunda, 2019).

There is a wide range of actions that can be taken to enforce the right to disconnect, businesses can customize their strategy to fit their unique set of circumstances. For example, the financial company Natixis has made a policy to encourage staff members to avoid accessing email on weekends and holidays. Similarly, Société Générale has unveiled a "Policy on the Proper Use of Electronic Messaging," complete with training courses meant to guarantee staff members recognize the significance of utilizing digital technologies responsibly. These programs demonstrate how the right to disconnect has two purposes: it serves as a safeguard for workers and an obligation for employers to maintain a secure and healthy workplace.

According to the above facts, France's legal system has established a solid legal framework to safeguard employees from violating their right to disconnect.

C. Right to Disconnect in Australia.

The "right to disconnect" law in Australia, which goes into effect on August 26, 2024, is a big step towards guaranteeing workers' work-life balance (Silva, 2024). This law, a part of the Fair Work Act, gives freedom for employees to decline work-related communications outside their designated working hours without fear of penalties, except for an unjustified rejection. The purpose of the law is to accept the growing trend of remote work and the COVID-19 pandemic, which have made it more difficult to distinguish between professional and personal life (Miller, 2024).

Employers are still permitted by law to communicate with their staff members after hours, but staff members have the right to disregard these communications unless it is fair for them to reply. What is considered fair or unreasonable contact depends on several factors, including the nature of the job, the purpose of the interaction, and any financial arrangements.

Employees are advised to speak with their managers directly if disagreements occur over communication during non-business hours. If two parties cannot achieve a settlement, the Fair Work Commission (FWC) may be consulted to negotiate or issue legally binding orders. Significant fines of up to A$19,000 for individuals and A$94,000 for companies can result from breaking FWC orders (Silva, 2024).

Unions and worker organizations support the law for fostering work-life balance and reducing stress. Its effects, however, may differ depending on the industry. For example, the financial sector has expressed doubts about its efficacy because of the heavy workloads that its personnel must handle (Treisman, 2024). Finally, the law aims to motivate workers with a culture change to establish boundaries and priorities for their well-being.

According to the above facts, Australia introduced a friendly legal framework to safeguard employees from violating the right to disconnect.

VI. COMPARATIVE ANALYSIS BETWEEN SRILANKA, FRANCE AND AUSTRALIA

The "right to disconnect" draws attention to substantial differences between the Australian, French, and Sri Lankan legal frameworks. Due to the absence of specific laws regarding this right, there is a systemic problem in Sri Lanka whereby employees—especially middle-level staff members like clerks and management assistants—work overtime without receiving wages. Their right to equality guaranteed by the Sri Lankan Constitution, and their right to leisure are being violated by this circumstance, currently, there is no legal framework for the right to disconnect.

France has firmly included the right to disconnect into its labour laws, requiring businesses with more than 50 employees to engage in policy negotiations to safeguard employees' leisure time. Maintaining a distinct boundary between work and leisure time encourages a better work-life balance. Concern about the need to save personal time in the digital age is reflected in Australia's recent law regarding the right to disconnect. That law was enforced in Australia on 26 August 2024 and similarly gives employees the freedom to refuse business-related contacts outside of work hours without facing penalties.

Although France and Australia have established legal structures to safeguard this right, Sri Lanka's labor laws have a critical loophole that exposes workers to exploitation.

VII. CONCLUSION

When comparing the legal systems in France, Australia, and Sri Lanka, it is clear that there is a big legal gap in Sri Lanka relating to the right to disconnect. In contrast to Australia, which recently enacted legislation granting comparable protections, and France, which has firmly included this right into its labor code, Sri Lanka does not have particular legal measures protecting workers from having to work longer than usual hours without getting paid. Employees' fundamental right to equality is also affected by this absence, which also affects their right to leisure.

To address this issue Sri Lanka should enact legislative changes that clearly define the right to disconnect. This would make it crucial for businesses, especially those in the IT and apparel sectors, to establish explicit working hours and respect workers' time. It is also important to develop enforcement measures, such as fines for non-compliance and methods for staff members to report violations. Protecting workers' rights and bringing Sri Lanka into compliance with international standards, would encourage a better work-life balance throughout Sri Lanka.

REFERENCES

[1]. CMS Legal, “Switching on to Switching Off: Disconnecting Employees in Europe?” 2018.

[2]. L. Lerouge, F. Trujillo, “Contribution to the Right to Disconnect from Work. Are France and Spain Examples for Other Countries and EU Law?” Europe Labour Law Journal, vol. 13(3), 2022, pp. 430 – 465.

[3]. *Miller, “Right to Disconnect: Will it Work? And What does it mean?”, UNSW SYDNEY, 2 April 2024.*

[4]. P. Secunda, “The Employee Right to Disconnect”, Notre Dame Journal of International and Comparative Law, vol 9 (1).

[5]. *Silva, “Australians Get Right to Disconnect After Hours”, BBC NEWS, 26 August 2024.*

[6]. R. Treisman, “Australia is the Latest Country to Give the Right to Disconnect After Hours”, NPR, 26 August 2024.

[7]. N. Wanigasinghe, “How Disconnect is Disconnection? A Critical Legal Analysis of The Employee Right to Disconnect”, 12 IRC KDU, 2019.

Legal aspects of Copyrights responding to Artificial Intelligence: A Comparative Analysis of EU and Sri Lanka.

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***Abstract*— The legal issues of copyright protection for works produced by artificial intelligence (AI) in Sri Lanka and the European Union (EU) are examined in this comparative research. The EU has taken a proactive approach to the problem, attempting to strike a balance between the benefits of AI and human creativity by taking a closer look at definitions of AI systems and AI-assisted outputs. On the other hand, the 2003 Intellectual Property Act (IPA) of Sri Lanka limits authorship to humans, leaving AI-generated works unclear. This study emphasizes how both regions' intellectual property rules need to change to effectively handle the breakthroughs in AI. The study aims to offer frameworks for improved regulation and protection of AI-generated intellectual property, safeguarding both innovation and societal interests. It does this by looking at current legislation, international treaties, and the developing nature of AI.**

Keywords—Artificial Intelligence, Copyright Protection, Intellectual Property, AI-generated Works, Comparative Legal Analysis.

I. INTRODUCTION

Automation, natural language processing, robotics, and machine learning are just a few of the cutting-edge technologies that artificial intelligence (AI) has brought to society and industry. But the incorporation of AI into creative processes has brought up significant legal issues, especially with regard to copyright and intellectual property (IP) protection. In order to address these concerns, the European Union (EU) has acknowledged the need for comprehensive regulation.With an emphasis on the requirements of originality and authorship, the EU AI Act seeks to make clear the copyright status of works generated by AI. This proactive approach strikes a balance between the value of AI contributions and human innovation by taking into account AI-assisted output and providing broader definitions of AI systems. On the other hand, the Sri Lankan Intellectual Property Act (IPA) of 2003 limits authorship to humans as specified in Section 5 of the Act, and does not specifically protect works created by AI. This restriction calls into question the copyright status of AI-generated works, highlighting the necessity of legislative changes to make room for AI breakthroughs. This study compares and contrasts the legal systems in the EU and Sri Lanka to

investigate how each region handles the protection of AI-generated works under copyright. In order to offer options that guarantee sufficient protection for intellectual property while promoting innovation and societal advancement, the study explores international conventions, current laws, and prospective revisions.

II. RESEARCH QUESTIONS

1. How does the Sri Lankan legal framework for copyright compare to that of the European Union regarding the protection of AI-generated works?

2. What specific gaps exist in the Sri Lankan Intellectual Property Act that hinder the recognition and protection of AI-generated content?

3. How can Sri Lanka adapt its legal framework to better align with international standards and effectively address the challenges posed by AI technologies in the creative domain?

III. RESEARCH PROBLEM

The existing copyright and intellectual property regimes face serious problems as a result of the rapid growth of artificial intelligence (AI) technology, especially regarding the legal standing and protection of works produced by AI. Since the Intellectual Property Act of 2003, limits authorship to humans, leaving works created by AI unclear, this study aims to fill the legal knowledge and regulation gap regarding AI-generated intellectual property in Sri Lanka. The European Union, on the other hand, has created a more thorough

legislative framework that aims to strike a balance between the preservation of human creativity and AI contributions and the interests of innovation.

In order to determine the significance of these variations for the defense of intellectual property rights and the encouragement of innovation, this study intends to investigate the differences between the legislative frameworks of the EU and Sri Lanka concerning the copyright status of works produced by artificial intelligence. The study aims to provide recommendations for legislative reform in Sri Lanka, safeguarding intellectual property rights while fostering an environment conducive to technological advancement and creativity.

IV.METHODOLOGY

The proposed study on the approaches taken by the Sri Lankan legal framework to govern copyrights in an era driven by Artificial Intelligence in comparison to that of the European Union Laws, will accommodate a qualitative research methodology approach. Accordingly, the study will examine the primary and secondary sources pertaining to the relevant fields focused by the study using the doctrinal research methodology and comparative research methodology.

Doctrinal research methodology is instrumental in examining the approaches taken by the Sri Lankan legal framework to govern copyrights in an era driven by Artificial Intelligence (AI), especially when compared to the European Union (EU) laws. This methodology focuses on the analysis of existing statutes, case law, regulations, and legal principles to understand and critique the legal landscape. Firstly, doctrinal research allows for a comprehensive analysis of Sri Lankan copyright laws, identifying how current legislation addresses (or fails to address) challenges posed by AI-generated works. By examining statutes such as the Sri Lankan Intellectual Property Act No. 36 of 2003, researchers can pinpoint specific provisions related to copyright protection and assess their applicability to AI-created content. Secondly, this methodology facilitates a comparative study by systematically reviewing relevant EU directives, regulations, and case law, such as the EU Copyright Directive (2019). This comparison highlights differences and similarities in legal approaches, providing insights into how the EU's more developed legal framework addresses issues like authorship, ownership, and the economic rights of AI-generated works. Lastly, doctrinal research helps identify the prevailing status within the Sri Lankan legal system when juxtaposed with the EU's robust copyright regime. By analysing judicial interpretations and legislative intentions, researchers can propose reforms to align Sri Lankan copyright laws with international standards, ensuring they remain effective in the evolving landscape of AI and digital innovation (EconomyNext, 2024).

Comparative research methodology is essential for examining how different legal frameworks address copyright issues in the era of artificial intelligence (AI). When applied to the study of Sri Lankan and European Union (EU) laws, this methodology allows for a systematic comparison of legal approaches, identifying both commonalities and divergences. The first step involves a detailed analysis of Sri Lanka's existing copyright laws, focusing on how they address AI-generated works, protection of intellectual property, and enforcement mechanisms. This analysis includes reviewing relevant legislation, case law, and policy documents. Similarly, the EU's legal framework is examined, with particular attention to the Directives and Regulations governing copyrights, as well as recent initiatives addressing the challenges posed by AI. The EU's approach often serves as a benchmark due to its comprehensive and evolving nature, making it a valuable point of reference. By comparing these two frameworks, researchers can identify a comparative insight as to strengths and weaknesses in Sri Lanka's laws relative to the EU's. This comparison not only highlights best practices but also provides insights into how Sri Lanka can adapt its legal framework to better address the complexities introduced by AI which would benefit in legal harmonization, policy improvement and protection of innovations. Overall, comparative research methodology offers a structured approach to understanding and improving the governance of copyrights in the context of AI, ensuring that Sri Lanka can effectively protect intellectual property in a rapidly evolving technological landscape.

This dual-method approach ensures a thorough examination of the legal frameworks and offers valuable insights for aligning Sri Lankan copyright laws with international standards. By analysing Sri Lanka's existing copyright legislation and comparing it with the comprehensive and evolving EU directives and regulations, the study will identify critical gaps, strengths, and weaknesses. This systematic comparison not only highlights best practices but also provides practical recommendations for reforming Sri Lankan copyright laws to better address the complexities introduced by AI-generated works. Ultimately, this approach aims to enhance the effectiveness via revision of laws and executing such within the legal framework of Sri Lanka's so as to protect intellectual property in the rapidly evolving technological landscape (Ariyadasa. A, 2019).

V. ANALYSIS AND DISCUSSION

A. European Union Copyright Framework for AI-Generated Works.

The EU has been at the forefront of developing laws and policies to address AI challenges across various sectors, including intellectual property. When it comes to AI-generated works, the EU recognizes their copyrightability in various legal aspects so as to avoid infringement of legal boundaries of intellectual property. It defines AI systems broadly as software developed using various techniques such as machine learning, logic-based approaches, and statistical methods to achieve specific human-defined objectives. These systems generate content, predictions, recommendations, or decisions. The challenge lies in determining whether these outputs deserve copyright protection. According to the Commission's 2021 proposal for an AI Act, an AI system means "software that can, for a given set of human-defined objectives, generate output such as content, predictions, recommendations, or decisions influencing the environments they interact with (Hugenholtz P.B and Quintais J.P, 2021).

The law thereupon grapples with whether works created with AI assistance also referred to as "AI-assisted output" is qualified for copyright protection which includes AI-generated art, poetry, and translations. Thereby, EU copyright law hinges on originality and authorship. For AI-generated works, the European Court of Justice (ECJ) emphasizes the presence of human creativity and free choices thereby, AI systems must exhibit a level of originality to qualify for protection. Also, traditionally, as copyright centres around human authors. the EU recognize flexible rules to accommodate AI-assisted output where the focus is on whether the work meets the criteria of a "work" under EU law (GAFFAR. H and ALBARASHDI S, 2024).

B. The Comparison between The European Union Legal Framework and Sri Lankan Legal Framework.

The EU aims to regulate artificial intelligence (AI) as part of its digital strategy in order to improve the environment for the advancement and application of this cutting-edge technology. Numerous advantages, including improved healthcare, cleaner and safer transportation, more effective manufacturing, and more affordable and sustainable energy, can be brought about by AI. The European Commission put up the first EU AI regulation framework in April 2021. It claims that AI systems that have a variety of uses are assessed and categorised based on the risk they present to consumers. There will be varying degrees of regulation depending on the danger levels. (EU AI Act: First regulation on Artificial intelligence, 2023).

The legal framework pertaining to works generated by AI is better developed in the EU. A comprehensive law governing information privacy in the European Union and the European Economic Area (EEA) is called the General Data Protection Regulation. (General Data Protection Regulation, 2018). The first comprehensive AI regulation in the world, the EU AI Act, will control AI use within the EU Information on particular court rulings pertaining to AI-generated works in the EU is, however, lacking. (EU AI Act: First regulation on Artificial intelligence, 2023).

AI systems that compromise fundamental rights or safety will be classified as high risk and split into two categories: AI programs utilised in goods covered by EU product safety regulations. Toys, aircraft, automobiles, medical equipment, lifts, and AI systems are among the particular industries that fall under this category and must be registered in an EU database. Critical infrastructure administration and operation Instruction and career development Workplace access, worker management, and self-employment Obtaining and taking advantage of vital private services as well as public services and advantages Law enforcement Management of migration, asylum, and border controls assistance with applying and interpreting the law. Every high-risk AI system will be evaluated both before and during its entire existence to ensure it is safe for use. It will be legal for people to complain to certain national authorities regarding AI systems. (EU AI Act: First regulation on Artificial intelligence, 2023).

Requirements for transparency While ChatGPT and other generative AI won't be categorised as high-risk, they will still need to abide with EU copyright laws and transparency standards: identifying the material as having been created by AI Developing the model to stop it from producing illicit material Disseminating copies of the training data that is protected by copyright High-impact general-purpose AI models (like the more sophisticated GPT-4) that could constitute a systemic danger would need to be thoroughly evaluated, and any significant events would need to be notified to the European Commission. (EU AI Act: First regulation on Artificial intelligence, 2023).

In Sri Lanka, the copyright protection laws governed under the Intellectual Property Act No.36 of 2003. (No.36,2003) The Legal Framework of Sri Lanka on Artificial Intelligence-generated works are not specifically covered by the Intellectual Property Act No. 36 of 2003. Nevertheless, evidence indicates that Sri Lanka's current legal system might not be sufficient to safeguard copyright holders' rights in items produced by artificial intelligence. There is a void in Sri Lankan law protecting AI-generated originality since it primarily addresses conventional kinds of creative works.

In order to address the issues raised by AI-generated works, the EU is taking a more sophisticated approach.The legal environment in Sri Lanka is more restrictive than that of the EU, which offers greater clarity and flexibility regarding fair use and data mining. 4. Nonetheless, both legal systems acknowledge the necessity of safeguarding intellectual property rights in content produced by AI. Final Thoughts In conclusion, a comparison of the EU's and Sri Lanka's copyright laws for works created using artificial intelligence demonstrates that each country has advantages and disadvantages. To address the issues raised by AI-generated works, Sri Lanka's legal system needs to be revised, even though the EU's approach is more thorough and sophisticated. To create a more effective legal system that balances artists' rights, further research is required.

VI. CONCLUSION

The copyright environment for AI-generated works varies greatly between the EU and Sri Lanka. The EU adopts a progressive stance, embracing AI's role in creation while stressing human involvement and creativity. Their copyright concept allows for greater freedom in AI-assisted outputs while also broadly defining AI systems. In contrast, Sri Lanka's legal system is more stringent. The present Intellectual Property Act does not expressly cover AI-generated works, which might leave them unprotected.

This contrast emphasizes the need for reform in Sri Lanka. Their legal structure must be tailored to the intricacies of AI-generated material. The EU's approach, which emphasizes uniqueness and flexible regulations for AI-assisted outputs, is a useful baseline.

Further research is crucial to develop a more effective legal system in Sri Lanka. This system should balance the rights of human creators with the realities of AI-driven innovation. By

finding this balance, Sri Lanka can foster a legal environment that encourages both creativity and technological advancement.

VII. RECOMMENDATIONS

Propose establishing a legal framework that clearly defines who holds the copyright in AI-generated works (e.g., the AI creator, the user, or the developer) and recommend creating guidelines for joint ownership in cases where AI collaborates with human creators, enhancing Protection Mechanisms. recommend introducing mechanisms for protecting the rights of creators of AI systems, ensuring they benefit from the commercial use of AI-generated works and suggest implementing policies to prevent misuse and unauthorized exploitation of AI-generated content.

Promoting Innovation and Creativity and recommend incentivizing innovation by providing tax breaks or grants for the development of AI technologies and creative industries and Suggest establishing bilateral agreements and partnerships to facilitate the exchange of knowledge and expertise between Sri Lanka and the EU.

REFERENCES

[1] Hugenholtz, P.B. and Quintais, J.P. (2021). Copyright and Artificial Creation: Does EU Copyright Law Protect AI-Assisted Output? IIC – International Review of Intellectual Property and Competition Law, 52. Doi: https://doi.org/10.1007/s40319-021-01115-0.

[2] GAFFAR, H. And ALBARASHDI, S. (2024). Copyright Protection for AI-Generated Works: Exploring Originality and Ownership in a Digital Landscape. Asian Journal of International Law, [online] pp.1–24. Doi: https://doi.org/10.1017/s2044251323000735.

[3] EconomyNext. (2024). Sri Lanka's copyright laws need to be updated for artificial intelligence: Lawyers. [online] Available at: https://economynext.com/sri-lankas-copyright-laws-need-to-be- updated-for-artificial-intelligence-lawyers-150509/ [Accessed 20 Jul. 2024].

[4]Ariyadasa, A. (2019). Protection of Copyright Owners and Authors Rights in the Internet: A Comparative Analysis of IP Law in Sri Lanka and EU Directives. [online] Ssrn.com. Available at: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3484677 [Accessed 20 Jul. 2024].

Analyzing the Factors Influencing the Persistence of Undergraduates at ABC Private Higher Education Institute

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***Abstract*— Student persistence in higher education is a crucial aspect for academic institutions worldwide, highlighting the need to understand the factors that contribute to this persistence, including academic achievement. This study aimed to analyze the factors influencing the persistence of undergraduates at ABC Private Higher Education Institute, with a focus on academic advising, peer support, and extracurricular activities. Data were collected from 291 undergraduates through questionnaires assessing academic advising, peer support, and extracurricular involvement. Statistical analysis revealed significant associations between academic advising and extracurricular activities as influential factors for both academic success and student persistence. The study emphasized that improved academic advising is critical for enhancing persistence rates and underscored the need for further analysis of financial barriers. Recommendations include expanding access to academic support services, fostering peer mentoring programs, and promoting balanced extracurricular involvement to create a supportive educational environment for all students.**

Keywords*— Student persistence, Peer support services, Extracurricular activities, Academic Advising

I. INTRODUCTION

A. Background of the Study

Student persistence refers to the ability and willingness of students to continue their education and achieve their academic goals despite challenges. In Sri Lanka, Higher Education Institutes play a vital role in molding students as future leaders skilled with advanced knowledge and skills that meet the industry requirements. Over the past decade, a notable increment in student enrolment has been observed because of the opening of new Private Higher Education Institutions in Sri Lanka. The growth of public and private educational offerings is leading to intense competition among private institutions to attract a more significant number of students as well as retain them until the course is completed [1]. Understanding the factors that influence student persistence is essential for institutions to develop effective strategies for student retention. Hence there is a need for Higher Education Institutions to understand and analyze the factors that affect the persistence and academic achievements of its students to retain the students as well as attract the market.

B. Significane of the Study

ABC Institute, known for its academic rigor and partnerships with foreign universities, faces a growing challenge in ensuring students complete their courses. At ABC Private Higher Education Institute in Sri Lanka, understanding the factors that influence undergraduate's ability to persist through their college education is essential.

This study aims to evaluate the factors influencing student persistence at ABC Institute, helping the institution develop targeted interventions and support systems to address student challenges and foster a more supportive learning environment. By identifying and addressing barriers to persistence, the study seeks to improve student well-being and academic performance. Its findings could inform institutional practices, influence policy decisions, and enhance overall student success in higher education. Ultimately, the research aims to foster a more inclusive and supportive environment that enhances academic achievement and personal development, helping students realize their full potential.

II. LITERATURE REVIEW

The literature on student persistence in higher education offers significant insights into the theories and factors that contribute to student retention. One of the most influential models in this domain is Tinto's model of student persistence, first introduced in 1975. Tinto's model reflects the ongoing decision-making process that undergraduates undergo throughout their academic journey, particularly in relation to whether they will persist or drop out of higher education. Tinto proposed that student persistence is influenced by both academic experiences and social integration within the institution [2]. Over time, this model has been widely utilized in higher education settings to understand and address student retention issues.

According to Tinto, students must develop both academic and social integration skills through formal and informal avenues to succeed. Formal academic integration includes activities

such as attending classes, conducting research, and participating in labs, while informal academic engagement involves interactions with faculty outside the classroom. These social and academic engagements are critical for student success, as higher levels of integration positively correlate with improved student persistence and graduation rates [3]. In addition, Tinto emphasized that students bring a set of prior academic experiences, goals, and commitments when entering university, and institutions need to align with these expectations to foster success. Faculty interaction, both inside and outside the classroom, is particularly influential in determining student persistence [4]. A lack of engagement with the academic system and faculty can contribute to students' struggles with persistence and their likelihood of dropping out [5].

Academic advising is another significant factor influencing student persistence. Academic advising provides students with essential guidance throughout their academic journey. According to Cuseo [6] academic advising is the most common student service linked to persistence. It helps students clarify their academic and career goals, navigate institutional requirements, and make informed decisions about their academic pathways [4]. Research shows that effective advising, which includes regular, personalized interactions between students and advisors, enhances students' chances of persisting in their studies and achieving timely degree completion [6]. Advising helps students develop academic plans, set clear goals, and overcome challenges that may hinder their progress [7]. Pascarella and Terenzini [8] also found that the absence of academic advising was associated with higher rates of student failure and dropout. Strengthening the advising relationship is crucial for improving students' academic success and overall satisfaction with their college experience

In addition to academic advising, peer relationships play a vital role in supporting student persistence. Peer relationships within higher education foster social support, emotional well-being, and a sense of belonging, which are all critical for students, particularly during times of transition or academic challenge. Positive peer interactions have been shown to positively impact students' grade point averages (GPA), intellectual self-esteem, and interpersonal skills [4] . For example, Larose, Bernier, and Tarabulsy [9] highlighted the importance of secure attachment styles in peer relationships, noting that students with secure attachments are more likely to seek help from their peers, which can lead to better academic performance. Furthermore, peer relationships provide students with opportunities for collaborative learning and academic mentoring, which enhance their learning experiences and contribute to their academic success [10].Peer interactions also help students build resilience and motivation to continue their studies, even when faced with obstacles.

Extracurricular activities also play a crucial role in enhancing student persistence. These activities provide students with opportunities for personal growth, skill enhancement, and social engagement outside the academic realm. Participation in extracurriculars, such as sports, clubs, volunteer work, and leadership roles, fosters a sense of belonging and social integration, both of which are closely linked to student persistence [11] . Engaging in extracurricular activities helps students connect with like-minded peers, form support networks, and develop transferable skills such as leadership, teamwork, and communication [12]. Contrary to the belief that extracurricular activities hinder academic performance, research by et al. [13] suggests that students engaged in these activities often exhibit higher levels of motivation, engagement, and academic achievement. Participation in extracurriculars can also provide students with a sense of purpose and direction, particularly when these activities align with their academic interests and career aspirations.

Finally, the literature highlights the importance of integrating academic performance, social factors, and institutional support services in fostering student persistence. Effective integration of these elements creates a supportive and inclusive learning environment that promotes student success. For example, peer mentorship programs can pair academically successful students with those facing challenges, providing both academic guidance and emotional support [14]. Similarly, academic advising can complement students' social integration efforts by helping them navigate course selection, academic planning, and career exploration. Involvement in extracurricular activities can also enhance students' academic performance by allowing them to apply classroom learning to real-world situations, develop leadership skills, and expand their social networks [15].

By recognizing the interdependence of academic performance, social integration, and institutional support, institutions can develop targeted interventions that address students' individual needs, thereby fostering persistence and success [16]. Creating a supportive campus environment that values both academic excellence and social engagement is essential for helping students overcome challenges, achieve their goals, and persist through to degree completion.

III. METHODOLOGY

The study employed a survey research strategy to gather quantitative data from a representative sample of undergraduate at ABC Private Higher Education Institute. The dependent variable of this study is student persistence, while the independent variables include social factors (peer relationships, extracurricular activities), institutional support services (academic advising), and academic performance (GPA).The research setting involved the academic, social, and institutional contexts within the institute. The research targeted students enrolled in the Higher National Diploma (HND) programs, specifically those active through the fourth semester of the March and September 2021 intakes, totaling 1,240 students. To ensure a 95% confidence level with a 5% margin of error, a sample size of 294 students was required. Out of the 400 questionnaires distributed, 291 were used for the final analysis.

IV. RESULTS

A. Sample

Between 2020 and 2021, the institution had approximately 1240 full-time and part-time undergraduate students. Data were from 400 students, of which 291 were selected for analysis. Rejections were primarily due to incomplete forms or lacking Higher National Diplomas (HND). Among the

participants, 169 were from Computing, 58 from Business Management, 24 from Biomedical Science and 40 from Quantity Surveying. Table 1.1 provides a breakdown of enrolment counts across different programs and intake periods for the specified years. It illustrates the number of students participating in the survey from each intake period.

Table I – Summary of the sample

		Intake				
		March 2020	September 2020	March 2021	September 2021	Total
Programme	Computing	49	39	43	38	169
	Biomedical Science	7	6	6	5	24
	Quantity Surveying	12	9	10	9	40
	Business Management	15	14	15	14	58
Total		83	68	74	66	291

In this study, the calculated Cronbach's Alpha coefficient was 0.761, indicating a moderate to high level of internal consistency among the items included in the measurement scale.

Table II: Cronchbach's Analysis for reliability

Case Processing Summary

		N	%
Cases	Valid	291	100.0
	Excluded[a]	0	.0
	Total	291	100.0

a. Listwise deletion based on all variables in the procedure.

Reliability Statistics

Cronbach's Alpha	N of Items
.761	15

B. Analyzing The Effect Of Peer Support Services, Social Factors, And Institutional Support Services Is On Academic Achievement And Persistence

Chi-square test was conducted to explore how significant the combined effect of academic performance, social factors, and institutional support services is on predicting both academic achievement and persistence.

TABLE III – CHI-SQUARE TESTS STATISTICS FOR PEER SUPPORT, EXTRA CURRICULAR ACTIVITY, ACADEMIC ADVISES VS ACADEMIC PERFORMANCES

Chi-Square Tests

Variable	Value	Asymptotic Significance (2-sided)
Peer Support	401.88	<0.000
Extracurricular Activity	281.47	<0.000
Academic Advising	586.21	<0.000

The Chi-square test results indicate that peer support, extracurricular activities, and academic advising all have significant associations with academic performance. Peer support shows the strongest association, with a Chi-square value of 401.88 and a p-value of <0.000, indicating it plays a crucial role in influencing students' academic success. Extracurricular activities also exhibit a significant relationship with academic performance (Chi-square = 281.47, p-value <0.000), suggesting that involvement in such activities can impact student outcomes. Academic advising, also shows a significant association ((Chi-square = 586.21, p-value < 0.000). This implies that academic advising, , is another important factor affecting academic performance. Overall, these findings highlight that non-academic factor like peer support and extracurricular activities, along with academic advising, significantly contribute to students' academic outcomes.

TABLE IV – CHI-SQUARE TESTS STATISTICS FOR PEER SUPPORT, EXTRA CURRICULAR ACTIVITY, ACADEMIC ADVISES VS PERSISTENCE

Chi-Square Tests

Variable	Value	Asymptotic Significance (2-sided)
Peer Support	11.26	0.589
Extracurricular Activity	21.22	0.020
Academic Advising	63.11	<0.000

The Chi-square results reveal varying associations between peer support, extracurricular activity, and academic advising with student persistence, the dependent variable. Peer support, with a Chi-square value of 11.26 and a p-value of 0.589, shows no statistically significant relationship with student persistence, suggesting it does not play a major role in influencing whether students continue their studies. However, extracurricular activity, with a Chi-square value of 21.22 and a p-value of 0.020, demonstrates a significant association, indicating that participation in extracurriculars positively impacts student persistence. Most notably, academic advising shows a strong and highly significant association with persistence, with a Chi-square value of 63.11 and a p-value of less than 0.000. This suggests that effective academic advising is crucial for supporting students in persisting with their education, making it a key factor in reducing dropout rates and enhancing student retention.

V. DISCUSSION

The significant association found between student persistence and academic advising aligns with previous research indicating that effective advising contributes to higher retention rates by assisting students in overcoming challenges [14] and addressing barriers such as academic difficulties, financial constraints, and personal issues [17]. Moreover, the association between academic achievement and advising underscores the importance of advisor-student interactions in fostering academic success through support, study skills development, and resource referrals [18].

The strong association between peer support and academic achievement is consistent with prior findings emphasizing the importance of peer networks in promoting success[19]. The study also confirms the association between extracurricular activities and academic performance, aligning with existing literature [20][21].

The results indicate that while peer support does not significantly influence student persistence, both extracurricular activities and academic advising have meaningful and statistically significant associations, with academic advising having a particularly strong positive impact. Chi-Square analysis further highlights the importance of academic services in student enrollment and persistence, aligning with previous research [22]

The study's findings also support the benefits of extracurricular activities for student engagement, consistent with Mahoney et al.[21] and Marsh & Kleitman [21]. However, the lack of a significant association between peer support and persistence contrasts with earlier studies [19], suggesting that peer support's influence on persistence may depend on contextual factors. Future research should investigate how peer support interacts with other elements, like academic services and extracurricular involvement, to affect student persistence.

VI. CONCLUSION

This research report examines the factors influencing student academic performance and enrollment at ABC Higher Education Institution. The findings reveal a significant association between academic service utilization and extracurricular activities with both academic achievement and persistence, underscoring the importance of comprehensive support services and engagement in extracurricular activities. While peer support positively influences academic success, it shows a non-significant association with persistence, indicating varying impacts. To enhance student outcomes, future research should further investigate these dynamics. Additionally, institutions should focus on improving academic advising, expanding support services, and promoting peer mentoring to create a supportive environment that fosters student persistence and success.

REFERENCES

[1] Jayasinghe, P.M.R.H., Prasad, P.V.C.,Premarathne K.H.H.K., & Madumali, M.V.B., (2023). Study on Student Satisfaction in Private Universities in Sri Lanka. doi:10.21203/rs.3.rs-2918094/v1

[2] Nicoletti, M. Do. (2019). Revisiting Tinto's theoretical dropout model. Higher Education Studies, 9(3), 52. doi:10.5539/hes.v9n3p52

[3] Chrysikos, A., Ahmed, E., & Ward, R. (2017). Analysis of Tinto's student integration theory in first-year undergraduate computing students of a UK Higher Education Institution. International Journal of Comparative Education and Development, 19(2/3), 97–121. doi:10.1108/ijced-10-2016-0019.

[4] Awadh, M. (2018). The relationship between the quality of academic advising and the perception of academic outcomes of Saudi College students. International Research in Higher Education, 3(4), 22. doi:10.5430/irhe.v3n4p22.

[5] Smith, W., Forbes, S., Robichaux-Davis, R., & Guarino, A. J. (2020). Self-Monitoring as a Personality Variable in Tinto's Theory of Integration. Advances in Social Sciences Research Journal, 7(1) 406-408.

[6] Cuseo, J. (2009). The empirical case for academic advising: Supporting student success through improved retention and program completion. NACADA Journal, 29(1), 6-42

[7] Habley, W. R., Bloom, J. L., & Robbins, S. B. (2012). Increasing persistence: Research-based strategies for college student success. John Wiley & Sons..

[8] Pascarella, E. T., & Terenzini, P. T. (2005). How college affects students: A third decade of research (Vol. 2). Jossey-Bass.

[9] Larose, S., Bernier, A., & Tarabulsy, G. M. (2005). Attachment state of mind, learning dispositions, and academic performance during the college transition. Developmental Psychology, 41, 281-289.

[10] Hernández, C., Chávez, A. F., & Collazo, Y. (2021). Peer support, belongingness, and college persistence among Latinx college students. Hispanic Journal of Behavioral Sciences, 43(2), 195-213.

[11] Denault, A. S., & Poulin, F. (2017). The role of extracurricular involvement in university persistence: A mixed-methods study. Journal of College Student Retention: Research, Theory & Practice, 19(2), 206-223.

[12] Schneider, A., & Stevenson, M. (2019). The relationship between extracurricular involvement and academic outcomes in higher education: A review of recent research. Research in Higher Education, 60(4), 445-464.

[13] Furlong, A., Cartmel, J., & Bigby, C. (2019). A review of the impact of extracurricular activity participation on student persistence in higher education. Journal of Higher Education Policy and Management, 41(6), 623-639

[14] Nutt, C. L. (2020). Advising to support student success. New Directions for Community Colleges, 2020(189), 47-58.

[15] Schneider, A., & Stevenson, M. (2019). The relationship between extracurricular involvement and academic outcomes in higher education: A review of recent research. Research in Higher Education, 60(4), 445-464.

[16] Campbell, C., & Nutt, C. L. (2008). The role of academic advising in student retention and persistence. About Campus, 13(6), 2-8.

[17] Grites, T. J. (2009). Supporting student retention through academic advising. In J. M. Braxton (Ed.), Reworking the Student Departure Puzzle (pp. 177–191). Vanderbilt University Press.

[18] Lowenstein, M. (2012). If advising is teaching, what do advisors teach? NACADA Journal, 32(1), 47–54.

[19] Fredricks, J. A., & Eccles, J. S. (2006). Extracurricular involvement and adolescent adjustment: Impact of duration, number of activities, and breadth of participation. Applied Developmental Science, 10(3), 132–146.

[20] Mahoney, J. L., Cairns, B. D., & Farmer, T. W. (2003). Promoting interpersonal competence and educational success through extracurricular activity participation. Journal of Educational Psychology, 95(2), 409–418.

[21] Marsh, H. W., & Kleitman, S. (2002). Extracurricular school activities: The good, the bad, and the nonlinear. Harvard Educational Review, 72(4), 464–514.

[22] Lowenstein, M. (2012). If advising is teaching, what do advisors teach? NACADA Journal, 32(1), 47–54.

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Edge-Magic Total Labelling of Cyclic and Bicyclic Bridge Graphs

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Abstract- **Edge-magic total labelling is an interesting area in graph theory with significant implications. In this study, we explore the edge-magic total labelling of cyclic graphs with n vertices and bicyclic bridge graphs with 2n vertices, demonstrating that these graphs can be labelled with a magic sum k=2n. An edge- magic total labelling on a graph G is a one-to-one map λ from $V(G) \cup E(G)$ onto the integers 1,2,…,$v + e$, where $v = |V(G)|$ and $e = |E(G)|$. This mapping has the property that for any edge xy, $\lambda(x) + \lambda(xy) + \lambda(y) = k$, a constant called the magic sum of G. Graphs that satisfy this condition are termed edge-magic. For cyclic graphs with n vertices, we start by labelling the vertices from 1 to n in a clockwise direction. Edges are then labelled by starting from the $(n-1)^{th}$ edge, labelling from 1 to $2n-3$ in steps of 2 in an anti-clockwise direction, and the n^{th} edge is labelled $n-1$. Considering any edge xy with adjacent vertices labelled $m+1$ and m, the edge receives the label $2n-2m-1$. The magic sum k is calculated as $m + (m+1) + 2(n-m) - 1 = 2n$, proving that cyclic graphs with n vertices are edge-magic with the magic sum $2n$. For bicyclic bridge graphs, two cyclic graphs each with n vertices are connected by a bridge. Each cycle is labelled similarly to the cyclic graph. The bridge connects the vertex labelled 1 of each cycle and is labelled $2n-2$. For the bridge edge, the magic sum remains $2n$. Thus, the bicyclic bridge graphs are also edge-magic with the magic sum $2n$. This study confirms that both cyclic graphs with n vertices and bicyclic bridge graphs with $2n$ vertices can achieve edge-magic total labelling with a consistent magic sum of $2n$, contributing to the broader understanding of labelling in graph theory.**

Keywords- bicyclic bridge graph, edge-magic total labelling, graph theory, magic sum, vertex labelling

Introduction

Graph theory, a significant area in discrete mathematics, includes various labeling problems. One such problem is the edge-magic total labeling, a concept that assigns unique integers to the vertices and edges of a graph such that the sum of the labels of an edge and its endpoints is constant. This constant sum is known as the magic sum.

The objective of this study is to explore and prove that every cyclic graph with n vertices and every bicyclic bridge graph with $2n$ vertices can be labeled as an edge- magic total labeling with the magic sum $k = 2n$. The scope of this research includes all cyclic and bicyclic bridge graphs, focusing on their labeling patterns and validating the magic sum.

Previous research in edge-magic labeling has primarily focused on simple and known graph structures such as paths and cycles. Works by Enomoto et al. (1998) and Wallis (2001) have laid foundational concepts in magic and edge-magic labelings. However, comprehensive studies on more complex structures, particularly bicyclic bridge graphs, remain limited, highlighting the need for this research.

The methodology involves constructing specific labeling schemes for cyclic graphs with n vertices and bicyclic bridge graphs with $2n$ vertices. For cyclic graphs, vertices are labeled sequentially in a clockwise direction, and edges are labeled in an anti-clockwise direction. For bicyclic bridge graphs, the labeling of two cyclic subgraphs and their connecting bridge is examined. Each step in the labeling process is designed to maintain the edge-magic condition.

This study confirms that both cyclic and bicyclic bridge graphs can achieve an edge-magic total labeling with the magic sum $k = 2n$. This finding not only extends the class of graphs known to be edge-magic but also provides a structured method for labeling these graphs.

Materials and Methods

The methodology consists of detailed steps for labeling both cyclic graphs and bicyclic bridge graphs.

For a cyclic graph with n vertices:

1. Vertex Labeling: Vertices are labeled from 1 to n in a clockwise direction.
2. Edge Labeling: Edges are labeled starting from the $(n-1)^{th}$ edge, assigning labels 1 to $2n-3$ in steps of 2 in an anti-clockwise direction. The nth edge is labeled $n-1$.

For bicyclic bridge graphs with $2n$ vertices:

1. Subgraph Labeling: Each cyclic subgraph is labeled as described above.
2. Bridge Labeling: The bridge connecting vertex 1 of each subgraph is labeled $2n-2$.
3.

Edge-Magic Total Labelings

An edge-magic total labelings on a graph G is a one-to-one map λ from $V(G) \cup E(G)$ onto the integers 1,2,…,$v + e$, where $v = |V(G)|$ and $e = |E(G)|$, with the property that, given any edge xy,

$\lambda(x) + \lambda(xy) + \lambda(y) = k$ for some constant k; In other words, $wt(xy) = k$ for any choice of edge xy. Then k is called the magic sum of G.

The labeling ensures that the sum of the labels for each edge and its endpoints equals $2n$. The methodology obeys to the principles set forth by previous studies while

introducing new labeling techniques for complex structures.

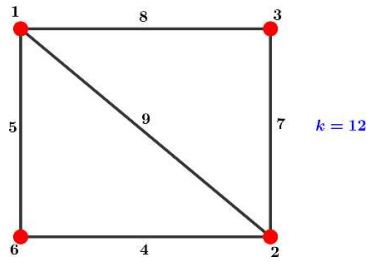

Figure 1:- Explanation of the edge-magic total labeling

Bicyclic Bridge Graph

The n-bicyclic bridge graph is a simple graph obtaining by connecting two copies of a cycle graph C_n by a bridge.

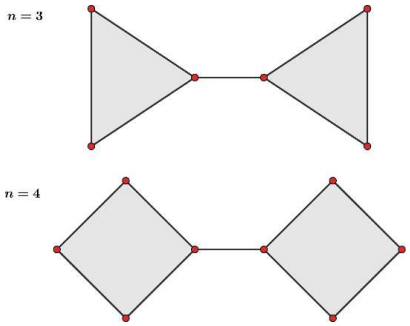

Figure 2: Bicyclic Bridge graph

Results and Discussion

The results demonstrate that the proposed labelling scheme effectively assigns labels such that the magic sum $k = 2n$ is achieved for both cyclic and bicyclic bridge graphs.

Results

Cyclic Graphs: For any edge xy with adjacent vertices labeled $m + 1$ and m, the edge label is $2n - 2m - 1$, ensuring the magic sum $k = 2n$.

Every cyclic graph with n vertices can be labeled as an edge-magic total labeling with the magic sum $(k) = 2n$

Proof: Consider a cyclic graph C_n with n vertices $v_1, v_2, \dots, v_n$ arranged in a cycle. Label the vertices in a clockwise direction from 1 to n, i.e., v_i is labelled as i for $1 \le i \le n$. For the edges of C_n, start labelling from the edge between v_n and v_1 and proceed in an anti-clockwise direction.

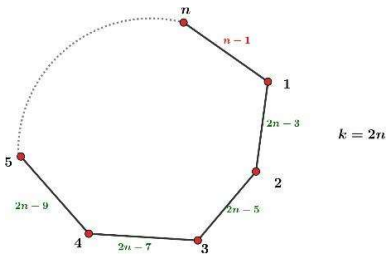

Figure 3: Labelled Cycle Graph

Label edges as follows. Label the edge between v_1 and v_2 as 1. Label the edge between v_2 and v_3 as 3. Continue labelling in this sequence until you reach the edge between $v_{n-1}$and v_n which is labelled as $2n - 3$. Finally, label the edge between v_n and v_1 as $n - 1$. Consider any edge $e = v_iv_{i+1}$ where v_i is labelled i and v_{i+1} is labelled $i + 1$. The edge e is labelled with $2n - (i + (i + 1)) = 2n - 2i - 1$, except for the edge between v_n and v_1, which is labelled $n - 1$.

Let's calculate the magic sum k for any other edge $e = v_iv_{i+1}$: For any edge $e = v_iv_{i+1}$(excluding the edge between v_n and v_1):

$$k = label\ (v_i) + label\ (v_{i+1}) + label\ (e)$$

$$k = i + (i + 1) + (2n - 2i - 1) = i + i + 1 + 2n - 2i - 1 = 2n$$

For the edge between v_n and v_1:

$$label\ (v_n) = n, label\ (v_1) = 1, label\ (e) = n - 1$$

$$k = n + 1 + (n - 1) = 2n$$

Bicyclic Bridge Graphs: The bridge edge, labeled $2n - 2$, maintains the magic sum $k = 2n$ for any edge within the graph.

every bicyclic graph bridge with $2n$ vertices can be labeled as an edge-magic total labeling with the magic sum (k) is $=2n$

Proof: For the first cycle C_n: Let the vertices be labelled $1,2, \dots, n$ in clockwise order. Lable the edges such that: Edge between vertices i and $i + 1$ is labelled $2i - 1$(for $i = 1,2, \dots, n - 1$). The edge between vertices n and 1 is labelled $n - 1$.

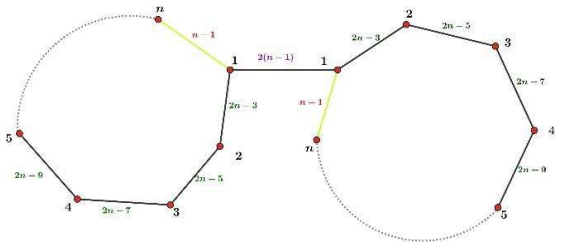

Figure 4: Labelled Bicyclic bridge graph

Apply the same labelling scheme as for the first cycle. The bridge connecting vertices 1 from each cycle is labelled with $2n - 2$.

For an edge e in the first cycle: Suppose the edge connects vertices labelled m and $m + 1$. Edge label is $2n - 2m - 1$. Sum of labels: $m + (m + 1) + (2n - 2m - 1) = 2n$. This verifies that for edges in each cycle, the magic sum is $2n$. For the bridge edge, endpoints are labelled 1 and 1. Edge label is $2n - 2$. Sum of labels are $1 + 1 + (2n - 2) = 2n$. This confirms that the bridge edge also maintains the magic sum $2n$.

By following the labelling strategy for both cycles and the bridge, and verifying the magic sum for all edges in the bicyclic bridge graph, it is established that every bicyclic bridge graph with $2n$ vertices can indeed be labeled as an edge-magic total labeling with the magic sum $k = 2n$.

Discussion

These results confirm the hypothesis that cyclic and bicyclic bridge graphs can be edge-magic with the specified magic sum. The findings align with established theories in graph labelling, extending their application to more complex graph structures. The study successfully proves that cyclic graphs with n vertices and bicyclic bridge graphs with $2n$ vertices can be labeled with an edge-magic total labeling achieving a magic sum of $2n$. The methodology may require adjustments for graphs with additional complexities or constraints not covered in this study. Further research could explore these exceptions. This work enhances the understanding of edge-magic total labeling, offering potential applications in network design, error detection, and coding theory where such labeling properties are advantageous.

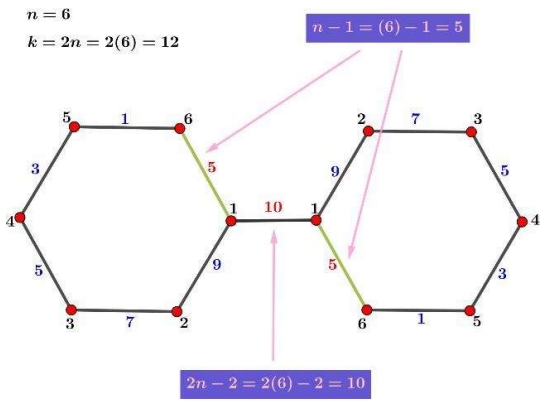

Figure 5: Detailed example

REFERENCES

[1] Petr, K. (2004). Magic Labelings of Graphs, *Ph.D. Thesis, Technical University of Ostrava*, https://www.fei.vsb.cz/export/sites/fei/470/.content/galerie-souboru/zaverecnePrace/disertacni/PetrKovar

Evaluating the Efficacy of Machine Learning Compared to Traditional Methods in Kidney Calcification Diagnosis: A Comprehensive Review

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***Abstract*— Phosphorus dysregulation is a major factor in kidney calcification, a serious consequence of chronic kidney disease (CKD) caused by mineral imbalance. Effective treatment of kidney calcification is needed to improve patient outcomes in chronic kidney disease. This study compares the efficiency, accuracy, flexibility and capability of conventional and machine learning (ML) based methods for appropriate care in managing this disease. To manage mineral levels and prevent calcification, conventional treatments such as dietary modifications, phosphate binders, dialysis, and phosphorus-regulating drugs are still critical. Emerging machine learning techniques such as data-driven therapeutic optimization and predictive modeling provide a possible alternative to these traditional approaches. ML can identify high-risk individuals and deliver customized therapies, predict disease courses, enable early treatment, and improve long-term calcification management by using sophisticated algorithms and large datasets. This study hypothesizes that compared to traditional methods alone, ML-driven approaches can improve treatment outcomes by providing more accurate, data-informed and patient-specific care. In addition, the ability of ML to match the unique characteristics of each patient may reduce problems and improve the quality of life of CKD patients. The results of this study aim to improve traditional approaches and encourage proactive patient care by guiding the use of machine learning as a complementary tool in the management of chronic kidney disease.**

Keywords—Kidney calcification diagnosis, Machine learning efficacy, Traditional diagnostic methods, chronic kidney disease (CKD), Comparative analysis, Predictive modeling in healthcare

I. INTRODUCTION

Kidney Calcification is the process of depositing Calcium within the kidney tissues. Kidney Calcification process occurs due to the imbalance of Calcium and Phosphorus. In this research review. However, these the kidneys play a vital role in regulating the above-mentioned minerals and maintaining the balance of these minerals under normal physiological conditions. When considering the factors for the Kidney Calcification Although there have been improvements in the treatment of CKD, current approaches to controlling kidney calcification lack personalized solutions that would take into consideration patient variability in the progression of the disease and the patient's characteristics. Most traditional approaches are predominantly more or less retaliatory, focusing on managing the signs instead of identifying and avoiding adverse outcomes. Besides, they are usually developed based on protocols other than patient-specific information, which might be ineffective. This lack of precision and personalization is a clear testament to the need for new methods that can identify high-risk calcification areas in their nascent stages and then provide unique treatment recommendations.

This study mainly focusses on the following research questions.

i. How kidney calcification affects different ages of people including percentages, symptoms, penalties.

ii. What are the factors that cause to deposit Calcium in Kidneys and identify the contribution of Phosphorus and its ions?

iii. Machine learning solutions for the related problem?

This research recommends the inclusion of machine learning (ML) algorithms such as Supervised Learning Techniques [1], Semi-Supervised Convolutional Neural Network(CNN) Algorithms [2], [3], image processing techniques [4], Hybrid Deep Learning Algorithm [5], Reinforcement Learning and prediction [6], [7], [8], and GAN based detection [9] in the existing CKD treatments to improve the approach towards the management of kidney calcification. From the foregoing, ML brings in specific strengths regarding prospect evaluation and other analytical tasks that involve large datasets, and which are not easily solved by other methods. Through the application of ML, the healthcare providers could estimate the risk of calcification progression, screen out at-risk patients, and choose the proper treatment plans according to the patients' characteristics. This proactive approach is expected to increase the treatment accuracy, facilitate early response, and improve the CKD patients' prognosis. The purpose of this work is to assess and compare the effectiveness of the classical and ML strategies in the treatment of kidney calcification in patients with CKD. It supposes that care based on ML-based methods can be more effective than traditional methods solely.

This paper presents an overview of evaluating the efficacy of machine learning compared to traditional methods in kidney calcification diagnosis. Section 2 outlines the experimental evidence and previous calculations kind of information regarding the mentioned research questions. Section 3 covers the methodology parts mentioning how to manage the difficulties while doing this review. All in all, Section 5 summarizes the main conclusions and suggested some decisions based on engaging the machine learning and calcification.

II. Experimental Evidence

A. *Classify the influence of Kidney Calsification based on the age categories*

Chronic kidney disease, which can contribute to kidney calcification, is a significant public health concern, affecting approximately 13% of the global adult population [10]. The prevalence of chronic kidney disease increases sharply with age, with the highest burden observed in individuals over the age of 70 [11], [12]. Younger individuals, although less likely to develop kidney calcification, are not immune to its effects. Researchers have found that even in the early stages of kidney disease, the risk of cardiovascular events and mortality increases, underscoring the importance of early detection and intervention [13]. Epidemiological studies have shown that the global prevalence of chronic kidney disease exceeds 10% of the general population, amounting to over 800 million individuals worldwide [14].

Kidney calcification is often associated with the progression of chronic kidney disease, and can accelerate the deterioration of renal function [12], [15]. The symptoms of kidney calcification can range from mild discomfort to more severe complications, such as kidney stones, chronic kidney disease, persistent back pain, frequent urination, and decreased urine output and even kidney failure [15]. These symptoms can be particularly pronounced in older individuals, as the aging process can intensify the impact of kidney calcification [15]. Furthermore, kidney calcification has been linked to an increased risk of cardiovascular events, acute kidney injury, and progression to end-stage kidney disease, all of which can have severe consequences for patients, regardless of age [16], [12].

TABLE I. How kidney calcification affects different age groups

Age Group	**Causes and Risk Factors**	**Potential Consequences**
Neonates and Infants	Prematurity, Genetic disorders	Risk of renal impairment, growth delay
Children and Adolescents	Genetic disorders, metabolic conditions	Long-term risk of chronic kidney disease
Young Adults (20s-40s)	Kidney stones, hyperparathyroidism	Kidney damage, impaired renal function
Middle-Aged Adults (40s-60s)	Age-related changes, Underlying health conditions	Contributes to overall kidney decline
Elderly (Over 65)	Age-related changes, Vascular calcifications	Increased risk of kidney decline, frailty

In this case, several types of calcification types can be identified. Among them, one type is Arterial calcification, which is caused by atherosclerosis disease. and also, research has found that older people often have both Abdominal Aortic Calcification (AAC) and osteoporosis at the same time. [17] Doctors diagnose osteoporosis by measuring bone mineral density with dual-energy x-ray absorptiometry (DXA). This method has gained widespread acceptance. DXA technology also captures vertebral fracture assessment (VFA) images along with BMD. These images offer a cost-effective way to diagnose AAC. From this method, it can be understood that image processing techniques can be used to process these VFA images. Regarding the information of the mentioned research paper, there is a technique: when using the image processing technique, these types of patients can be added, they should be infected with calcification and after infestation, identify and treat for osteoporosis.

The focus of the research presented in this thesis is to determine the actual AAC rate in VFA images acquired in single-energy mode. The topic is divided into two main parts. In the first part, a method for identifying and quantifying AAC in VFA images is proposed and evaluated on several images. In the second part, the performance of single- and dual-energy VFA imaging is investigated for detecting uniformly distributed calcifications. The mentioned information in this research paper gives a clear picture of how to use medical images to get more accurate results. Medical images are very important in diagnosing and treating many medical conditions. Medical image processing and analysis helps to convert random images into quantifiable images suitable for analysis and mining and extract large amounts of information to support medical diagnosis. Different imaging techniques have been developed over the past decades. Examples are CT, US, Magnetic Resonance Imaging (MRI), and other tomographic techniques such as single photon emission computed tomography (SPECT) and positron emission tomography (PET) Images acquired with various medical imaging techniques are degraded or/or during they are taking it. or subjected to deformations. Consequently, extracting information for quantification requires at least some initial image processing.

Another Research about Immune-related secretory proteins linking chronic kidney disease to calcific aortic valve disease based on comprehensive bioinformatics analysis and machine learning [18]. In this study, focus Three raw expression profile data sets for calcific aortic value disease (CAVD) and control groups (GSE12644, GSE51472, and GSE83453) and two datasets for CKD patients (GSE37171 and GSE66494) were obtained from the GEO database. The battle function of the “SVA” package in R (version 4.2.1) was used to batch-correct the CAVD data sets, resulting in 34 calcified and 23 control samples. Differentially expressed genes (DEGs) identified using the “Limma” packages with the thresholds of adjusted $p \leq 0.05$ and $|\log2 \text{ (fold change)}| \geq 1$ for CAVD, and $|\log2 \text{ (fold change)}| \geq 0.585$ for CKD. DEGs were visualized using “ggplot2” and “pheatmap” packages. Weighted gene co-expression network analysis (WGCNA) was performed to identify major module genes. The steps included calculating the absolute deviation (MAD) of each gene, removing genes with MAD of 0, using the “goodSamplesGenes” function to test genes and samples, performing scale-free coexpression networks with soft threshold power (β =) 5), and examining

the relationship between modules and quality. Highly connected modules were identified, and hidden proteins were obtained from the Human Protein Atlas. Protein–protein interaction (PPI) networks were constructed using the STRING database and visualized using a Cystoscope. The MCODE plug-in was used to identify critical modules. Using the DAVID database, a functional enrichment analysis was performed that displayed the results through bubble diagrams and circos plots. Connectivity map (cMAP) analysis identified potential small molecule drugs for the treatment of CAVD. The least absolute shrinkage selection operator (LASSO) algorithm and random forest (RF) algorithm were used to identify candidate biomarkers for machine learning and develop a diagnostic model. The "glmnet" package was used for LASSO, and the "randomForest" package was used for RF. Overlapping genes in both models were defined as hub genes for the CKD-associated CAVD model.

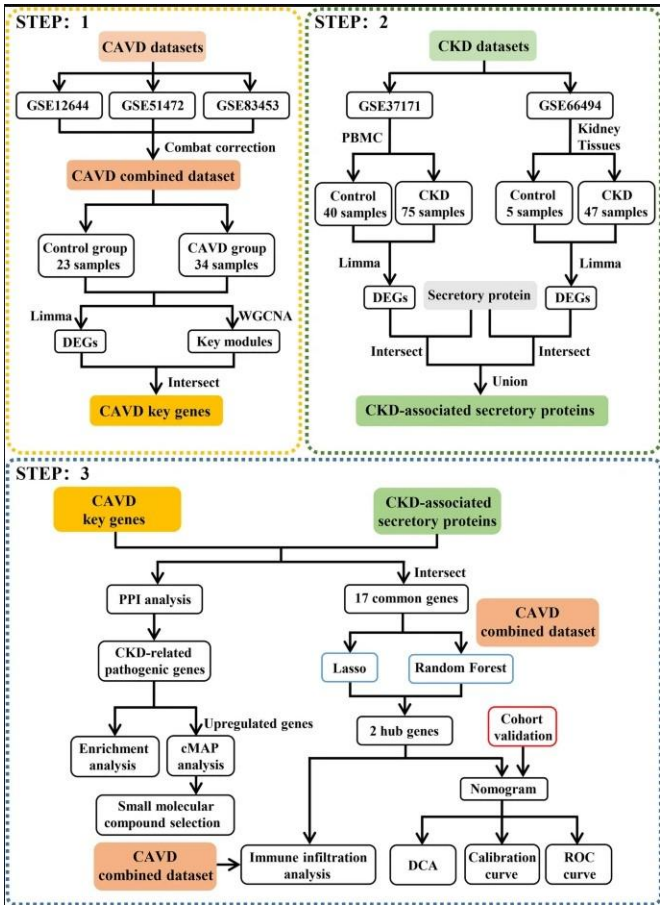

Fig. 1: Flow chart design of the proposed system

B. *Factors that cause to deposit Calcium in The kidneys*

Hypercalcemia, which is a high calcium level in the blood mainly causes kidney-based calcification. Calcium, phosphate, parathyroid hormone(PTH), and vitamin D are highly affected by kidney-based diseases [19]. Abnormal mineral metabolism of calcium (Ca) and phosphate (P) often makes a massive impact on bone loss and increases vascular calcification [13]. Another major factor for kidney-based calcification is Hyperphosphatemia in the blood. Under this developing the vascular calcification via several mechanisms: 1. VSMC Transition: This method explains vascular smooth muscle cells change from their usual muscle-like state to bone-like state and then start depositing the minerals, facilitated by specific sodium-dependent phosphate transports. 2. VSMC Apoptosis: High levels of phosphate in the blood causes these muscle cells to die and contribute to calcification. 3. Inhibition of Monocyte/Macrophage Differentiation: Hyperphosphatemia prevents certain immune cells from becoming osteoclast-like cells that could help to remove calcium deposits. 4. Elevated FGF23 Levels: this explains the important points like increased levels of fibroblast growth factor 23, a hormone that regulates phosphate, are associated with calcification. 5. Decreased Klotho Expression: Lower levels of Klotho protein, cause vascular calcification [20]. Hyperparathyroidism(PHPT) is another factor for kidney-based calcification [21]. Renal Tubular Acidosis (RTA) is another factor that highly affects kidney-based calcification. This causes the urine to have an acid level, which can cause the accumulation of calcium in the kidneys [22]. The Medullary Sponge Kidney is a rare developmental anomaly of the kidneys [23] and this is a congenital disorder where cysts form in the medullary and papillary regions of the kidneys and it tends to the calcification. Primary Hyperoxaluria: this is a rare genetic disorder that causes overproduction of oxalate, which combines with calcium to produce calcium oxalate and deposits in the kidneys [24]. Milk-Alkali Syndrome: take calcium and absorbable alkali, typically overuse calcium supplements or antacids, so this can lead to hypercalcemia and kidney calcification [25]. Then, Genetic Disorders: these genetic disordering situations can be caused by nephrocalcinosis [26]. Among them, the major reason for this kidney-based calcification is high phosphate levels in the human blood and high doses of Vitamin D [27].

C. *Machine Learning solution for kidney calsification*

In this section, the AI and ML solution for hyperphosphatemia has been reviewed [28]. This study had been aimed to categorize patients with chronic kidney disease (CKD) into distinct subgroups using a Gaussian mixture model (GMM) based on key biomarkers: phosphate, hemoglobin, logFerritin, and TSAT are recommended to be presented in ASM on Integrated Monthly Reports. Since the aim was to identify three clusters, this number was used to calculate both the mean cluster distance and the BIC to confirm the choice. These clusters were then compared in terms of their mortality and biomarker statuses.

The patients were first categorized into three groups; they were further categorized into two subgroups depending on whether they used OPB or not. The primary outcome studied was all-cause mortality and survival was described by the Kaplan–Meier method, and Cox regression models were used. Compared to the other clusters, biomarker level, and other clinic characteristics were found to be substantially different, which suggests the application of GMM as a promising method to identify more impactful patient subgroups for targeted therapies. In total, this work aimed to show that when patients with CKD are grouped by

specific biomarkers, some of them might be characterized by different outcomes, which proved the effectiveness of a more precise approach to patients' treatment.

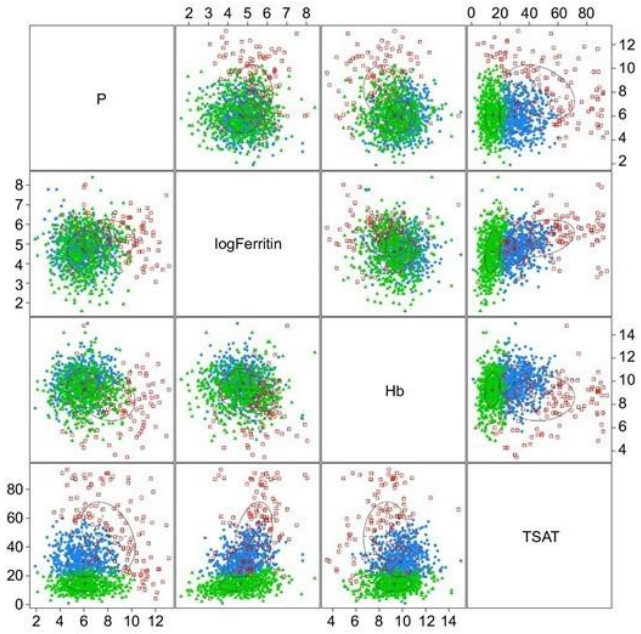

Fig. 2: This figure represents lots of each marker. Here each cluster has a different color Hb, hemoglobin; P, phosphate

Another research was conducted at Mayo Clinic Hospital including adult patients hospitalized between January 2009 and December 2013 and who had abnormal serum phosphate, all patients included Mayo Clinic Institutional Review Board [29]. Participants' data was stratified based on the serum phosphate levels: patients with hypophosphatemia of serum phosphate levels of ≤ 2. 4 mg/dL and patients with hyperphosphatemia had serum phosphate levels of ≥ 4. Participants' information was assessed from the hospital's electronic record and acquisition including demographics, co-mo mortalities, principal diagnoses, and inside laboratory findings within 24 hours of admissions. For the test and retest data, any item that was not answered by a participant was considered missing, and if less than 10% response was supplemented.

Consensus clustering by unsupervised machine learning was applied to define clinical clusters and the stability of the clustering was evaluated by different measures. To elaborate on the key features of each cluster, the first step was to calculate the standardized mean differences. Logistic regression on a cluster level and Cox proportional hazard regression tests were conducted to compare the differences in hospital and one-year mortality rates. All the analyses were conducted in the R environment and ConsensusClusterPlus for clustering. The objective of the study was to analyze mortality ratios and describe clinical patterns that relate to the identified patient groups.

Calcium deposits in the kidneys, known as nephrocalcinosis including supervised learning [3] for predictive modeling. Machine learning models can predict the level of phosphorus and its effect on kidney calcification by analyzing a variety of patient data including blood test results such as serum phosphate test [30]. Supervised learning algorithms, trained on labeled datasets using that can identify patterns and correlations between Phosphorus levels and calcification progression. By giving patient-specific data as input these supervised learning models can predict the future Phosphorus levels and their potential impact on kidney health. The conclusion of this study will help to promote the use of ML as an adjunctive tool for managing CKD, which will be the basis for more effective and timely approaches to patient care.

In a previous study on hypercalcemic detection[31], a Linear Regression approach was followed based on data gathered from clinical reports and other extractions. This study emphasized the fact that health practitioners, doctors, nurses, etc., are to be involved in collecting the data as well as dividing the work, which in return will enhance the detection results to 81% accuracy derived by the algorithm.

Developing this further, an extended blood phosphate level study can be carried out by using Cox's proportional-hazards models that could also be able to achieve both statistical testing and pattern finding on the phosphate concentration. In this context, the collection of data by a health care professional is very important. However, as about 80% of the total phosphorus in the human body is stored in bones and teeth, machine learning models for phosphorus distribution in the body are bound to have difficulties in getting highly accurate outputs due to limits in technologies and challenges in data gathering techniques.

Similarly, measuring the extra phosphate level in the blood using a urine test is the more accurate technique in physical bioscience. This research paper proves the importance of the testing purpose of the extra phosphate level in the blood [33]. Subsequently, the focus can be directed to Hyperoxaluria, where standard operating procedures are to be framed to accurately detect and measure genetic disorders associated with the disease. The research paper[34] describes some facts about this point. In this context, machine learning algorithms are divided into 3 parts,

- Supervised Learning
- Semi-Supervised Learning
- Unsupervised Learning

These methods each play a role: supervised methods predict calcification risk using labeled data, Unsupervised methods used to identify the patterns without labels, and then semi-supervised model leverage both. In this sense, Generative models help to identify underlying genetic factors while discriminative models enhance predictive accuracy. Using existing knowledge has an impact on making models better and more effective when there's not much data to work with. The best ways to measure performance and figure out networks help ensure accurate predictions. This is crucial because of the tricky connections between genetic and clinical factors that lead to kidney calcification. Phosphorus, primarily present as phosphate ions (PO4^3-), is crucial for bone health and energy production. Compared to the effects of hypertension[35] and diabetes[36] caused by CKD through metabolic and pressure-related mechanisms, phosphorus contributes mainly through mineral imbalance and subsequent

calcification. Phosphorus and calcification play a major role in CKD progression massively in the context of existing renal impairment where phosphate excretion is reduced [37].

The application of machine learning to address a solution to calcification is a critical role. The resultant model allows us to forecast the status of the kidney with the effect of calcification. To create the model, it is required to create a dataset including the data of the different patients. phosphorus levels were raised in CKD rats, and therefore there was enhanced vascular calcification [38]. It was ascertained from another similar study on rats that CKD promoted higher calcification of the blood vessels when these rats were fed on a diet containing high amounts of calcium and phosphorus coupled with calcitriol. A data set from the patients including different demographic variables should be developed to facilitate the analysis of Phosphorus levels. This dataset will enable classification of patients into different categories considering a threshold value and measuring the correlations [39]. When implementing the machine learning model, the usage of Biomarker data is essential, as it measures novel mediators like FGF23 and sclerostin along with routine markers such as serum phosphate. Not only Biomarker data, but Dialysis treatment records can also be used by capturing the information prescriptions, including frequency, duration, and parameters of the dialysis sessions.

III. Methodology

The systematic review of the studies included in the present paper was conducted following the PRISMA guidelines to provide transparent and exhaustive identification of the articles. To refine the search, set inclusion criteria was set to consider studies that investigated factors that led to calcium deposits in kidneys, patients' age in kidney calcification studies, and machine learning techniques in diagnosing or predicting kidney calcification. Exclusion criteria included the absence of data on kidney calcification or its association with machine learning, and the absence of age information on kidney calcification. For the present study, an extensive search was carried out in IEEE, Google Scholar, and PubMed databases without any restriction on the year of publication to include both the recent and the most significant literature. Terms such as "kidney calcification" "calcium deposit kidney" "machine learning" and "chronic kidney disease" were employed with the use of the Boolean operators and filters to narrow down the subject areas in nephrology and machine learning in healthcare. Subjects for the final analysis were identified through the title and abstract filtering, and full-text review of potentially relevant studies. Both the screening and full-text review stages were completed by two independent investigators to reduce bias, and discrepancies were discussed and resolved with a third reviewer when necessary. The data extraction process was done using a data extraction form where information concerning study characteristics, causes of kidney calcification, age groups most affected, and details of the machine learning models used to include the datasets, evaluation metrics and the performance of the models was recorded. Data synthesis was done narratively, based on the primary research questions; studies were grouped, and quantitative performance of machine learning algorithms was summarized for comparison. Last, a PRISMA flowchart is used to present the study identification and selection at different stages in this review, including the number of records identified, screened, excluded, and included.

A study of existing literature was conducted to identify relevant studies on kidney calcification and its relationship to age. Studies were included based on predefined criteria, which included,

- **Population -** Studies focusing on human subjects across different age groups.
- **Intervention/Exposure -** Presence or absence of kidney calcification.
- **Outcomes -** Prevalence, causes, symptoms, progression, treatment approaches, and long-term complications of kidney calcification.
- Subgroup analyses were performed to explore the impact of age on the outcomes of interest.

The difficulties and limitations faced throughout the study are as follows; The quality of the systematic review was inherently dependent on the quality of the included studies. Age is often correlated with other factors that can influence kidney calcification, such as diabetes, hypertension, medication use, and lifestyle factors. It can be challenging to completely isolate the independent effect of age. The methods used to diagnose and assess kidney calcification (e.g., imaging techniques, laboratory tests) may vary across studies, potentially introducing measurement error and making comparisons difficult. Even within specific age groups, there can be significant heterogeneity in terms of genetics, environmental exposures, and overall health status, which can influence the findings. There are also limited high-quality studies specifically focusing on kidney calcification in certain age groups.

IV. Results & Discussion

The financial burden associated with kidney calcification can be significant, with direct and indirect costs including hospitalization, treatment, missed work, and medication expenses [15]. This burden is particularly pronounced in low- and middle-income countries, which often lack the resources and infrastructure to effectively manage chronic kidney disease and its associated complications [14].

With the current level of development, some of these factors are identifiable to a certain degree using machine learning-based systems, while others evade the immediate scope of direct prediction through these systems. This latter limitation highlights the involvement of medical professionals in most situations where machine learning may be employed, since their expertise would be significant in interpreting such complex factors as may have been overlooked by automated systems.

For example, gene-based prediction of calcification is far more accurate and amenable to automation. Gene-based factors are extremely rare causes of calcification, and thus less frequent for large patient populations. Despite the rarity, gene-based machine learning models provide a promising avenue toward more accurate outcomes. This approach requires extended feature input since more observations across each feature strengthen the predictive accuracy of the model. Research indicates that parameters and features derived from blood reports are most useful in developing predictive models in the progression of chronic kidney disease. Notably, a linear regression (LR) model built based on these features can model CKD progression with high accuracy [40]. Thus, integrated data can enhance machine learning performance within medical practices most importantly from clinical reports. It is always necessary to check such a model with clinicians.

Glomerular Filtration Rate (GFR), Serum Phosphorus levels, Serum Calcium Levels, Serum Bicarbonate levels Parathyroid Hormone (PTH) levels, and Demographic information such as male or female are examples of the parameters that have been taken from the blood reports to create the Linear regression model.

	Total patients	Serum Phosphorus <4.5mg/dl	Serum Phosphorus >4.5mg/dl
Number	184	107	77
Age, years	69±12	72±12	65±13[a]
Sex, male/female	91/93	59/48	32/45
Smokers, %	17	15	21
Diabetes, %	30	33	27
Baseline glomerular filtration rate, ml/min/1.73m^2	15.2±5.6	17.6±5.4	11.9±3.8[b]
Body mass index, kg/m^2	29.7±5.6	29.4±5.2	30.1±6.2
Follow-up time, median (quartiles), days	303 (218-391)	305 (250-395)	297 (165-370)
Systolic blood pressure, mmHg	158±20	156±20	161±20
Diastolic blood pressure, mmHg	88±12	87±12	91±12[a]
Mean arterial pressure, mmHg	112±13	110±13	114±13[a]
Haemoglobin, g/dl	11.9±1.1	12.3±1.1	11.5±1.1[c]
Plasma albumin, g/dl	4.04±0.36	4.09±0.32	3.98±0.39[a]
Serum total calcium, mg/dl	9.32±0.66	9.50±0.44	9.05±0.81[c]
Serum phosphorus, mg/dl	4.43±1.01	3.76±0.47	5.35±0.82[c]
Serum bicarbonate, mmol/l	22.3±2.6	23.2±2.5	20.9±2.0[c]
PTH, pg/ml	372±259	295±217	479±275[c]
Proteinuria, mg/24 h	1.775±1.779	1.257±1.359	2.447±2.009[a]
Total urinary excretion of phosphorus, mg/24 h	464±155	450±145	480±275
Urinary phosphorus excretion /GFR, mg/24l/ml/min	37±17	29±12	48±19[c]
Fractional excretion of phosphorus, %	44±10	43±11	46±10
Total urinary excretion of calcium, mg/24h	38±27	38±26	37±27
Urinary calcium excretion index	0.16±0.14	0.13±0.11	0.19±0.17[b]
Protein catabolic rate (PNNA), g/kg/day	0.80±0.21	0.80±0.21	0.80±0.20
Patients on diuretics, %	58	48	71[b]
Patients with phosphorus binders at the beginning/end of the study, %	57/84	44/75	74/100[c]
Patients with vitamin D, %	14	10	20

Fig. 3: Clinical and biochemical characteristics of the study group as a whole and per subgroup according to serum phosphorus levels [40]

The following research was performed on two different methods of testing the correlation between serum PTH concentration and serum phosphate levels [41]. In the first method, the classical linear regression analysis was used, and a Graph was plotted when serum PTH is on the Y axis and phosphate on the X axis, it was observed that the R-value was 0. 27 and p<0. 001. This means that the two variables move in the same direction but with a very small amount of increase; hence it points to a weak positive correlation. In the second method, an analysis of variance and multiple regression on Random Forest (RF) findings was used, and mathematical models for the changes in PTH resulting from changes in serum phosphate concentration were developed. It is necessary to originate random variations in serum phosphate level, from -3 mg/dl to +3 mg/dl, after which the difference in the estimated PTH levels before and after is determined. As such, this analysis clearly revealed that fluctuations in serum phosphate correlate more with PTH with an R-value of 0. Consequently, the findings have given a value of 77 and a p-value <0. 001. Based on these analyses one could postulate that for a decrease in serum phosphate by 2 mg/dl the change of PTH could be +50 to -250 pg/ml.

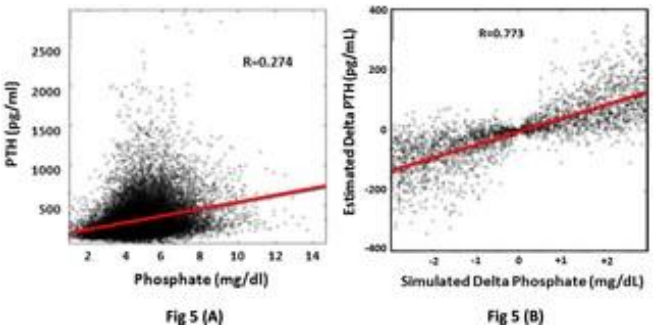

Fig. 4: Based on the above-mentioned research Fig 5(A) this test correlates the concentration of serum PTH and phosphate concentration. D mimic Fig 5(B) How the estimated change of PTH concentrates in response to a simulated change of the serum phosphate concentration

V. Conclusion

Given the widespread occurrence of kidney calcification and its potential to adversely impact individuals, especially older adults, implementing strategies for early detection and targeted interventions is important to minimize the consequences of this condition across different age groups. By addressing kidney calcification through a multifaceted approach, healthcare systems can assist in improving patient outcomes, reduce the societal and economic burden, and eventually enhance the quality of life for those affected. As previously discussed, number of approaches have been taken to address the kidney calcification problem. Based on the research reviewed so far, it can be revealed that machine learning is more reliable and precise in identifying the degree of calcification in the kidney than clinicians' evaluation. However, expert medical opinions and manual evaluations could never be underappreciated for their more global and contextual perspective on the matter at hand; on the other hand, as observed, machine learning models for the same task of calcification detection and quantification seem to be more accurate as well as consistent. It is also worth emphasizing that these models are based on the availability of vast amounts of data and the use of algorithmic

approaches which allow for better identification of patterns and possible correlations that are hard to detect by ordinary human logic, thus improving the accuracy of diagnostics and forecasts in comparison to exclusive reliance on a clinician's expertise. Further, advancements in machine learning techniques imply fast data processing compared to a human and are rather accurate besides consisting of large-scale solutions applicable to a wide range of clinical settings. For this reason, continuing the use of machine learning approaches in the practice of calcification could enhance the process of diagnostics and correspondingly stimulate patients' outcomes.

REFERENCES

[1] H. Zhu *et al.*, "Machine Learning for the Prevalence and Severity of Coronary Artery Calcification in Nondialysis Chronic Kidney Disease Patients: A Chinese Large Cohort Study," *J. Thorac. Imaging*, vol. 37, no. 6, p. 401, Nov. 2022, doi: 10.1097/RTI.0000000000000657.

[2] "A semi-supervised CNN learning method with pseudo-class labels for vascular calcification detection on low dose CT scans." Accessed: Jul. 27, 2024. [Online]. Available: https://www.spiedigitallibrary.org/conference-proceedings-of-spie/10950/109501L/A-semi-supervised-CNN-learning-method-with-pseudo-class-labels/10.1117/12.2513228.full

[3] J. Liu, J. Yao, M. Bagheri, V. Sandfort, and R. M. Summers, "A Semi-Supervised CNN Learning Method with Pseudo-class Labels for Atherosclerotic Vascular Calcification Detection," in *2019 IEEE 16th International Symposium on Biomedical Imaging (ISBI 2019)*, Apr. 2019, pp. 780–783. doi: 10.1109/ISBI.2019.8759189.

[4] M. Mansouri, "Machine learning analysis of calcifications on CT-scan to predict abdominal aortic aneurysm rupture," Jun. 2022, Accessed: Jul. 26, 2024. [Online]. Available: https://papyrus.bib.umontreal.ca/xmlui/handle/1866/27181

[5] K. Venkatrao and S. Kareemulla, "HDLNET: A Hybrid Deep Learning Network Model With Intelligent IOT for Detection and Classification of Chronic Kidney Disease," *IEEE Access*, vol. 11, pp. 99638–99652, 2023, doi: 10.1109/ACCESS.2023.3312183.

[6] "Artificial intelligence–guided precision treatment of chronic kidney disease–mineral bone disorder - Gaweda - 2022 - CPT: Pharmacometrics & Systems Pharmacology - Wiley Online Library." Accessed: Jul. 27, 2024. [Online]. Available: https://ascpt.onlinelibrary.wiley.com/doi/full/10.1002/psp4.12843

[7] A. Gaweda, M. Brier, and E. Lederer, "Leveraging Quantitative Systems Pharmacology and Artificial Intelligence to advance treatment of Chronic Kidney Disease Mineral Bone Disorder," *Am. J. Physiol.-Ren. Physiol.*, Jul. 2024, doi: 10.1152/ajprenal.00050.2024.

[8] "Application of artificial intelligence to chronic kidney disease mineral bone disorder | Clinical Kidney Journal | Oxford Academic." Accessed: Jul. 27, 2024. [Online]. Available: https://academic.oup.com/ckj/article/17/6/sfae143/7689216

[9] W. Preedanan *et al.*, "Improvement of Urinary Stone Segmentation Using GAN-Based Urinary Stones Inpainting Augmentation," *IEEE Access*, vol. 10, pp. 115131–115142, 2022, doi: 10.1109/ACCESS.2022.3218444.

[10] "Vascular calcification in chronic kidney disease", doi: https://doi.org/10.1053/j.ajkd.2003.12.005.

[11] M. Tonelli and M. Riella, "Chronic kidney disease and the aging population," *Néphrologie Thérapeutique*, vol. 10, no. 2, pp. 74–77, Apr. 2014, doi: 10.1016/j.nephro.2013.12.001.

[12] N. R. Hill *et al.*, "Global Prevalence of Chronic Kidney Disease – A Systematic Review and Meta-Analysis," *PLOS ONE*, vol. 11, no. 7, p. e0158765, Jul. 2016, doi: 10.1371/journal.pone.0158765.

[13] C. Viegas, N. Araújo, C. Marreiros, and D. Simes, "The interplay between mineral metabolism, vascular calcification and inflammation in Chronic Kidney Disease (CKD): challenging old concepts with new facts," *Aging*, vol. 11, no. 12, pp. 4274–4299, Jun. 2019, doi: 10.18632/aging.102046.

[14] C. P. Kovesdy, "Epidemiology of chronic kidney disease: an update 2022," *Kidney Int. Suppl.*, vol. 12, no. 1, pp. 7–11, Apr. 2022, doi: 10.1016/j.kisu.2021.11.003.

[15] V. Jha *et al.*, "Chronic kidney disease: global dimension and perspectives," *The Lancet*, vol. 382, no. 9888, pp. 260–272, Jul. 2013, doi: 10.1016/S0140-6736(13)60687-X.

[16] P. D. Evans and M. W. Taal, "Epidemiology and causes of chronic kidney disease," *Medicine (Baltimore)*, vol. 39, no. 7, pp. 402–406, Jul. 2011, doi: 10.1016/j.mpmed.2011.04.007.

[17] K. M. A. Elmasri, "A Robust Technique for the Detection and Quantification of Abdominal Aortic Calcification Using Dual Energy X-Ray Absorptiometry".

[18] E. Zhu *et al.*, "Screening of immune-related secretory proteins linking chronic kidney disease with calcific aortic valve disease based on comprehensive bioinformatics analysis and machine learning," *J. Transl. Med.*, vol. 21, no. 1, p. 359, Jun. 2023, doi: 10.1186/s12967-023-04171-x.

[19] K. A. Hruska, G. Saab, S. Mathew, and R. Lund, "PHOSPHORUS METABOLISM AND MANAGEMENT IN CHRONIC KIDNEY DISEASE: Renal Osteodystrophy, Phosphate Homeostasis, and Vascular Calcification," *Semin. Dial.*, vol. 20, no. 4, pp. 309–315, 2007, doi: 10.1111/j.1525-139X.2007.00300.x.

[20] J. Kendrick and M. Chonchol, "The Role of Phosphorus in the Development and Progression of Vascular Calcification," *Am. J. Kidney Dis.*, vol. 58, no. 5, pp. 826–834, Nov. 2011, doi: 10.1053/j.ajkd.2011.07.020.

[21] L. Rejnmark, P. Vestergaard, and L. Mosekilde, "Nephrolithiasis and Renal Calcifications in Primary Hyperparathyroidism," *J. Clin. Endocrinol. Metab.*, vol. 96, no. 8, pp. 2377–2385, Aug. 2011, doi: 10.1210/jc.2011-0569.

[22] J. Rodríguez Soriano, "Renal Tubular Acidosis: The Clinical Entity," *J. Am. Soc. Nephrol.*, vol. 13, no. 8, p. 2160, Aug. 2002, doi: 10.1097/01.ASN.0000023430.92674.E5.

[23] K. Bigosiński, M. Dubaj, and A. Dembowska, "Medullary sponge kidney - the mysterious name of a simple disease," *J. Educ. Health Sport*, vol. 12, no. 8, Art. no. 8, May 2022, doi: 10.12775/JEHS.2022.12.08.058.

[24] B. Hoppe, "An update on primary hyperoxaluria," *Nat. Rev. Nephrol.*, vol. 8, no. 8, pp. 467–475, Aug. 2012, doi: 10.1038/nrneph.2012.113.

[25] K. Yamagami *et al.*, "Pulmonary and gastric metastatic calcification due to milk-alkali syndrome: a case report," *CEN Case Rep.*, vol. 2, no. 2, pp. 209–214, Nov. 2013, doi: 10.1007/s13730-013-0066-1.

[26] "Inherited Arterial Calcification Syndromes: Etiologies and Treatment Concepts | Current Osteoporosis Reports." Accessed: Jul. 27, 2024. [Online]. Available: https://link.springer.com/article/10.1007/s11914-017-0370-3

[27] W. G. Goodman *et al.*, "Vascular calcification in chronic kidney disease," *Am. J. Kidney Dis.*, vol. 43, no. 3, pp. 572–579, Mar. 2004, doi: 10.1053/j.ajkd.2003.12.005.

[28] H. Morooka, A. Tanaka, D. Inaguma, and S. Maruyama, "Clustering phosphate and iron-related markers and prognosis in dialysis patients," *Clin. Kidney J.*, vol. 15, no. 2, pp. 328–337, Feb. 2022, doi: 10.1093/ckj/sfab207.

[29] C. Thongprayoon *et al.*, "Machine Learning Consensus Clustering Approach for Hospitalized Patients with Phosphate Derangements," *J. Clin. Med.*, vol. 10, no. 19, p. 4441, Sep. 2021, doi: 10.3390/jcm10194441.

[30] N. D. Toussaint and S. V. Badve, "Normalizing serum phosphate based on association, not causation? Lessons in dialysis should have taught us not to fix what we can't prove is broken," *Kidney Int.*, vol. 106, no. 2, pp. 195–199, Aug. 2024, doi: 10.1016/j.kint.2024.05.020.

[31] C. Bancal, F. Salipante, N. Hannas, S. Lumbroso, E. Cavalier, and D.-P. De Brauwere, "A new approach to assessing calcium status via a machine learning algorithm," *Clin. Chim. Acta*, vol. 539, pp. 198–205, Jan. 2023, doi: 10.1016/j.cca.2022.12.018.

[32] M. Tonelli, F. Sacks, M. Pfeffer, Z. Gao, and G. Curhan, "Relation Between Serum Phosphate Level and Cardiovascular Event Rate in People With Coronary Disease," *Circulation*, vol. 112, no. 17, pp. 2627–2633, Oct. 2005, doi: 10.1161/CIRCULATIONAHA.105.553198.

[33] "Phosphate in Blood: MedlinePlus Medical Test." Accessed: Aug. 04, 2024. [Online]. Available: https://medlineplus.gov/lab-tests/phosphate-in-blood/

[34] M. W. Libbrecht and W. S. Noble, "Machine learning applications in genetics and genomics," *Nat. Rev. Genet.*, vol. 16, no. 6, pp. 321–332, Jun. 2015, doi: 10.1038/nrg3920.

[35] M. Burnier and A. Damianaki, "Hypertension as Cardiovascular Risk Factor in Chronic Kidney Disease," *Circ. Res.*, vol. 132, no. 8, pp. 1050–1063, Apr. 2023, doi: 10.1161/CIRCRESAHA.122.321762.

[36] S. Gupta, M. Dominguez, and L. Golestaneh, "Diabetic Kidney Disease," *Med. Clin. North Am.*, vol. 107, no. 4, pp. 689–705, Jul. 2023, doi: 10.1016/j.mcna.2023.03.004.

[37] Z. Dai and X. Zhang, "Pathophysiology and Clinical Impacts of Chronic Kidney Disease on Coronary Artery Calcification," *J. Cardiovasc. Dev. Dis.*, vol. 10, no. 5, p. 207, May 2023, doi: 10.3390/jcdd10050207.

[38] Y. Wang, W. Han, Y. Zhong, W. Li, and Q. Liu, "Calcitriol combined with high-calcium and high-phosphorus diet induces vascular calcification model in CHRONIC KIDNEY DISEASE rats," *Environ. Toxicol.*, vol. 39, no. 3, pp. 1769–1779, Mar. 2024, doi: 10.1002/tox.24039.

[39] Y. Li *et al.*, "Machine learning based biomarker discovery for chronic kidney disease–mineral and bone disorder (CKD-MBD)," *BMC Med. Inform. Decis. Mak.*, vol. 24, no. 1, p. 36, Feb. 2024, doi: 10.1186/s12911-024-02421-6.

[40] "Asociación entre fósforo sérico y progresión de la enfermedad renal crónica avanzada," *Nefrología*, no. 31, Nov. 2011, doi: 10.3265/Nefrologia.pre2011.Sep.11089.

[41] M. Rodriguez *et al.*, "A New Data Analysis System to Quantify Associations between Biochemical Parameters of Chronic Kidney Disease-Mineral Bone Disease," *PLOS ONE*, vol. 11, no. 1, p. e0146801, Jan. 2016, doi: 10.1371/journal.pone.0146801.

Systematic Review of Smart Home Automation Technologies Based on IoT

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***Abstract*— The rapid evolution of IoT technologies has changed smart home automation, improving residential convenience, energy efficiency, and security. Even with these advancements, a thorough implementation and use of IoT in smart homes still needs further thorough assessment, especially when it comes to unresolved issues and new constraints. This critical analysis reviews present IoT- based smart home automation studies in areas like security structures, energy control, blockchain utilization, anomaly spotting, and user verification, as well as advancements in load tracking, activity identification, and intrusion detection. While some research covers topics like energy harvesting and cybersecurity, there is a lack of comprehensive, methodologically rigorous evaluations of the limitations and compatibility of these technologies. This review categorizes and assesses the quality of research methods used in articles published from January 2017 to June 2024, finding that only a small number of studies meet rigorous research criteria. The results emphasize the importance of established methods and innovative strategies like federated learning for protecting data privacy, using AI-driven anomaly detection, and harnessing blockchain for IoT security to tackle scalability, privacy, and real-time adaptability challenges. This review aims to aid in the advancement of IoT technologies in smart homes by pinpointing research gaps and proposing future pathways for more resilient, efficient, and user-centric solutions, ultimately boosting the wider adoption and improvement of IoT technologies in residential settings.**

***Keywords*— Internet of Things, Smart Home Automation, Security Frameworks, Energy Efficiency, Blockchain, Machine Learning.**

I. Introduction

The idea of IoT first emerged in 1982 with a vending machine being linked to the internet, followed by Mark Weiser's vision in 1992, which led to the adoption of RFID technology [1]. IoT, seen as the third wave of the internet, aims to interconnect objects globally. Widely used in industries, manufacturing, and homes, IoT now involves more connected devices than people on Earth, significantly transforming production, daily life, and energy management in diverse fields, including agriculture [2].

IoT devices configure themselves, identify nearby objects, and share environmental data such as light, motion, sound, and temperature. By embedding intelligence, these systems not only respond to their surroundings but also learn behaviors, enabling applications that personalize and enhance user experiences. However, IoT devices still face significant challenges related to computational capacity, energy usage, and storage, impacting both efficiency and security solutions. These issues are compounded by factors like battery constraints, scalability, and accessibility—elements that blend IoT and Wireless Sensor Networks (WSNs) but limit more robust security implementations [3].

The IoT sector has experienced unprecedented growth, with its value soaring from $1.90 billion in 2018 to $925.2 billion by 2023, and it is projected to reach $6 trillion by 2025. This growth highlights the expanding applications of IoT, from smart homes to city-wide infrastructures for monitoring traffic, environmental conditions, and public utilities [4]. In smart cities, for instance, French glass containers equipped with sensors notify when they are full, while in the U.S., garbage cans alert municipalities when they require emptying—streamlining services and reducing environmental impact [4].

In this review, we focus on smart home automation through IoT, evaluating how IoT-embedded technologies such as blockchain and cybersecurity are integrated. Smart home technologies are poised to meet rising demands for improved living standards among diverse demographics, particularly the elderly, who will represent 21% of the global population by 2040 [5]. These intelligent systems continuously collect and analyze data to enhance home management, achieving benefits such as heightened security through smart locks, cameras, and video calls. The integration of control panels enables residents to manage systems for climate control and energy efficiency effortlessly.

The review delves into key IoT applications that improve convenience, efficiency, and privacy, including assistive features like automated kitchens and bathrooms, optimized laundry systems, and interconnected living areas that support

communication, entertainment, and work. The incorporation of smart technology also facilitates better financial management by linking users with online services for budget tracking, energy cost savings, and predictive maintenance. In examining the current state of research, this review identifies both advancements and limitations, such as privacy risks from pervasive data collection and security challenges in multi-device ecosystems [6]. Furthermore, while technologies like blockchain provide decentralized security solutions, there remains a pressing need for privacy-preserving mechanisms that protect sensitive information in these connected environments [5], [17].

These advancements promise to transform not only energy management and security but also the quality of life, urging future research to address the emerging challenges and further enhance the reliability and scalability of IoT technologies within smart homes.

II. Literature Review

This literature review examines key areas in IoT-based smart home automation, encompassing advancements in energy management, anomaly detection, security, network architecture, and assistive technologies. Through a critical review, this section identifies both current capabilities and significant challenges, emphasizing the importance of secure, adaptive, and scalable solutions to meet emerging demands in smart home automation.

A. Energy Management and Efficiency

Smart home systems focus on enhancing energy efficiency through monitoring and managing the energy use of household devices and Smart homes can improve automation and energy efficiency by adding additional smart devices and sensors, which can optimize the performance of household appliances. These technologies assist in automatically controlling appliances, increasing the efficiency of homes. They also spot inefficient or defective devices and deduce patterns of behavior such as occupancy and sleep [7]. Methods for monitoring loads, essential for controlling energy consumption, are categorized into two types, as shown in Fig 1.

- **Intrusive Load Monitoring (ILM)** utilizes hardware and involves installing sensors on appliances for accurate energy monitoring. It is reliable but costly due to multiple sensors.
- **Non-Intrusive Load Monitoring (NILM)** utilizes software. Also uses a single sensor, like a smart meter, to monitor overall energy use. It is cost-effective but less accurate in identifying individual appliance consumption.

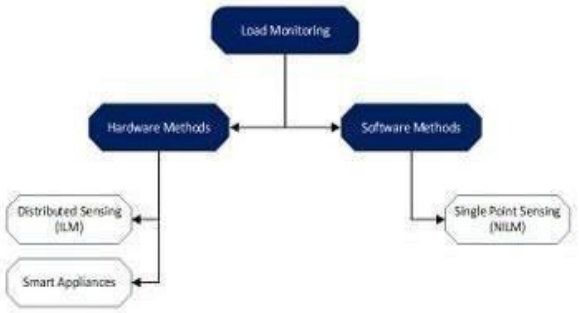

Figure 1. Methods of Load Monitoring

Heterogeneous energy harvesting (IHEH) techniques are crucial for enhancing energy efficiency in smart homes by capturing and converting waste energy—such as thermal, piezoelectric, and light energy—into usable electricity with a combined efficiency of 90%. These methods improve power management by storing harvested energy in batteries for use by sensors and appliances, reducing energy costs and supporting sustainable energy management. In real- time applications, IHEH can convert waste thermal energy from appliances like air conditioners into electricity, showcasing significant energy savings and efficiency improvements in everyday household operations. This integration offers a scalable and user-friendly solution for energy efficiency in smart homes [8].

Energy grid sustainability, reliability, and flexibility are enhanced by IoT-powered energy management systems. These systems have the capability to incorporate decentralized renewable energy sources, supply instant information for improved decision-making, and assist in automated control measures to boost energy efficiency. Yet, the heightened connectivity in IoT systems also poses cybersecurity challenges, as addressing potential vulnerabilities is crucial to safeguarding the security and reliability of smart energy grids [9].

B. Anomaly Detection and Privacy

Anomaly detection in smart homes tracks user behavior with IoT devices to spot unusual activities. It adapts to different conditions like time and temperature, achieving over 90% accuracy in tests but needs more training data for rare events. Privacy is essential. Anonymizing data from various homes protects user information while still allowing for effective anomaly detection. Collecting data from multiple homes helps improve accuracy but must be done carefully to maintain privacy. In short, successful anomaly detection in smart homes combines behavior tracking, adaptation, and strong privacy protections [10].

Smart home systems heavily rely on Wi-Fi networks, making them vulnerable to sniffing attacks where data packets are intercepted. These attacks exploit Wi-Fi's broadcasting nature and are difficult to detect due to minimal logging. Detection methods include host-based and network-based approaches. Host-based methods use agents on devices to monitor network activity, comparing

MAC addresses detect anomalies but are challenged by diverse IoT operating systems like Contiki and TinyOS. Network-based methods analyze traffic patterns, using challenge-based techniques with specific tests or measurement-based analysis for anomalies. Machine learning enhances detection by training on network data, with ensemble learning notably effective. This approach improves accuracy, making it practical for securing smart home environments against sophisticated attackers [11].

The research [12] describes a platform such as in figure 2, that detects anomalous operations in home IoT devices by using behaviors of similar users, without sharing private information. It models in-home activities such as state transitions based on sensor values and device states, detecting anomalies by comparing current operations to stored sequences. To address insufficient training data, the platform leverages behaviors of similar users such as room temperature and device operation times through anonymous communication, using Tor to ensure sender privacy. This approach maintains high detection accuracy by utilizing similar user behaviors while protecting individual privacy.

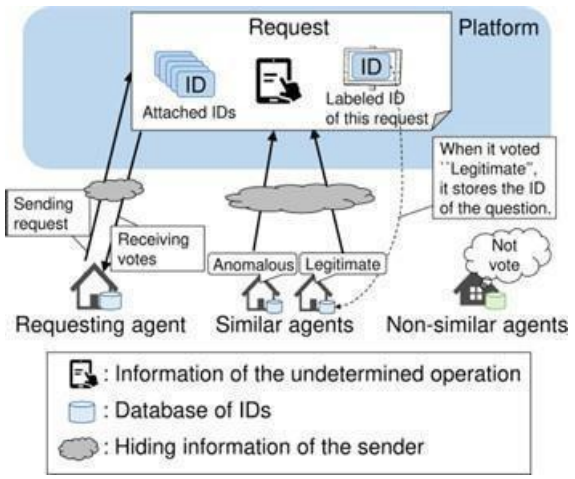

Figure 2. Overview of the Proposed Platform

The paper [13] presents an advanced anomaly detection system for IoT-based smart homes. It employs the Harmony-Enhanced Extra Trees (HEET) model, which integrates the Harmony Search Algorithm with the Extra Trees Classifier to optimize hyperparameters, enhancing classification accuracy. Tested on real-time data from 105 IoT devices, the system effectively detects anomalies across various configurations. Emphasizing user privacy, the IDS prevents unauthorized access and data breaches by ensuring accurate intrusion detection. The open-source availability of the model code underscores a commitment to transparency and collaborative security improvements, further safeguarding smart home environments.

C. Security and Privacy Mechanisms

Smart Home Systems (SHS) enhance household convenience and efficiency but pose significant security and privacy risks. Device diversity complicates secure data transmission and storage, and the lack of standardized interfaces and communication protocols from various vendors exacerbates security risks. Essential measures include using evaluation models like OCTAVE and dynamic security assessments to identify vulnerabilities and propose countermeasures. Improving communication protocols like ZigBee, Bluetooth Low Energy, and LoRaWAN is crucial to prevent unauthorized access and data breaches. Robust security and privacy mechanisms are vital for protecting SHS from potential threats and ensuring user privacy [14].

[15] Research identifies critical vulnerabilities in smart home systems, including outdated protocols, weak encryption, limited storage and processing capabilities, insecure applications, poor authentication mechanisms, and firmware failures. These vulnerabilities can lead to cyber-attacks like DoS, eavesdropping, impersonation, device hijacking, spoofing, and DDoS attacks. Addressing these issues requires secure communication protocols, regular software updates, robust encryption techniques, and user education on best security practices.

Smart home systems predominantly rely on Wi-Fi networks to function, making them susceptible to various attacks, including sniffing. Sniffing involves intercepting and capturing data packets traveling over a network, often exploiting the wireless broadcasting feature of Wi-Fi networks. This vulnerability is particularly pronounced in IoT devices due to challenges in credential management and the passive nature of sniffing attacks, which generate minimal logs and are thus difficult to detect [11].

To protect smart-home IoT devices from attacks like MQTT attacks, the study proposes an optimized Machine Learning (ML) model to detect network intrusions. The approach includes evaluating 22 ML algorithms, incorporating automatic feature engineering, and addressing data imbalance with resampling techniques. The best-performing model, the Generalized Linear Model (GLM) with random over-sampling, achieved 100% accuracy and f-score. Automatic feature engineering enhanced performance by 38.9% and reduced detection time by 67.7%. Also, the empirical study underscores the necessity of robust intrusion detection systems (IDS) for securing MQTT-based smart home networks against cyber threats [16].

Blockchain technology improves smart home security by establishing a decentralized and unchangeable system for overseeing IoT devices. This method guarantees data integrity, confidentiality, and availability by using a distributed ledger, which gets rid of weak points and lessens possible vulnerabilities. Various levels of accessibility and security are provided by different types of blockchains such as public, private, and consortium. By employing cryptographic methods, blockchain ensures the security of transactions and device interactions, halting unauthorized entry while upholding trust. While still in its early stages, the utilization of blockchain in smart homes

shows potential in resolving privacy and security issues within IoT environments [17]. In figure 3 displays how the smart home systems based on blockchain.

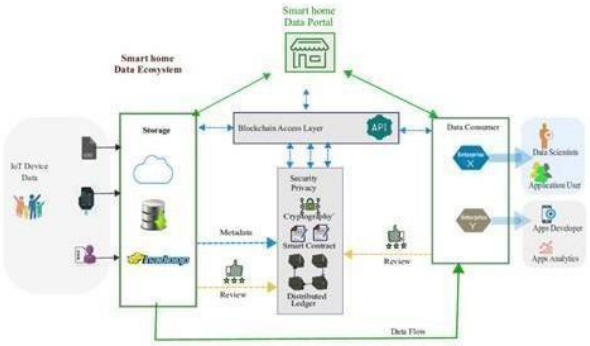

Figure 3. Blockchain-Based Smart Home System

The proposed privacy-preserving mechanism for smart homes employs Ethereum blockchain and edge computing to enhance energy management securely. Edge servers act as local blockchain miners, aggregating data from IoT devices. The blockchain ensures decentralized data management through smart contracts, which enforce Attribute-Based Access Control (ABAC) automatically. Differential privacy adds noise to data before it is transmitted to the cloud, protecting individual privacy while maintaining data utility. Smart contracts automate and enforce security policies. The framework aims to ensure confidentiality, integrity, and availability, demonstrating resilience against cyber threats and improved efficiency and security compared to existing models [18].

D. Network Architecture and Authentication

The research [19] emphasizes the critical need for a secure and efficient communication framework. The proposed architecture integrates LoRa technology to enhance the range and reliability of smart home networks. It includes a layered approach, separating physical, data link, network, and application layers to streamline communication and enhance security. For authentication, the scheme employs robust cryptographic techniques to ensure secure device enrollment and data exchange. This approach mitigates risks associated with unauthorized access and data breaches, thereby ensuring a secure smart home environment. The architecture and authentication methods are designed to be scalable, supporting the growing number of IoT devices in smart homes.

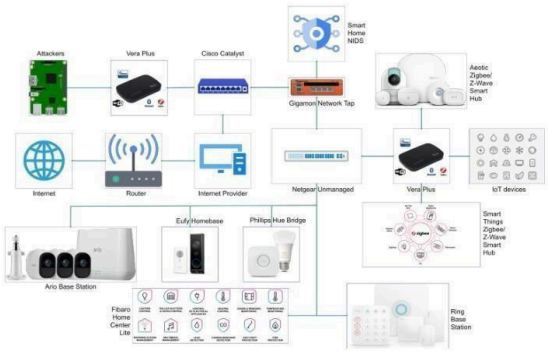

Figure 4. Smart Home Network Architecture

The paper proposes a remote user authentication protocol tailored for smart home environments, focusing on lightweight and privacy-preserving methods. Network architecture involves three main entities: the user, the gateway, and the smart device. Communication between these entities is conducted over secure channels, ensuring data integrity and confidentiality. The protocol leverages elliptic curve cryptography (ECC) for secure key exchanges and Advanced Encryption Standard (AES) for encrypting sensitive data. Temporal identities are used to maintain anonymity and prevent tracking of the user across different sessions. The authentication process is designed to resist various attacks, including man-in-the-middle, replay, and smart device capture attacks, by ensuring key freshness and forward secrecy. The formal security analysis conducted using the AVISPA tool confirms the protocol's robustness against potential vulnerabilities [20].

There is a three-layer network architecture for the Living Lab Gateway (LLG). The first layer connects all devices through a KNX infrastructure. The second layer translates these connections into IP datagrams, protected by a firewall. The third layer uses Docker and Kubernetes in the cloud to ensure flexibility and scalability. For authentication, the LLG uses JSON Web Tokens (JWT) and HTTPS for secure communication, storing passwords as hashed strings with the sha256 algorithm. This setup ensures a secure, scalable, and flexible system for managing smart home devices [21].

E. Assistive Technologies and Applications

A novel framework for IoT-based appliance recognition in smart homes significantly advances smart home automation systems. Integrating both training and inference processes, it incorporates diverse loads within the monitoring system. Data collected from home sensors are processed using an advanced feature extraction algorithm, deriving ten statistical features such as mean, standard deviation, and kurtosis. The framework employs feed-forward neural networks (FFNN), long short-term memory (LSTM) networks, and support vector machines (SVM) to enhance recognition accuracy. It allows customization of training and prediction parameters for adaptability. Innovations include handling imbalanced data classes, conducting feature importance analysis, and ensuring scalability for various home sizes. Evaluations demonstrate high accuracy, real-time efficiency, and user satisfaction, marking it as a significant advancement in smart home automation [22].

“CBASH: A CareBot-Assisted Smart Home System Architecture to Support Aging-in-Place" [23] showcases advanced IoT integration in smart home automation for elderly care. It combines a comprehensive sensor network

with versatile CareBot and a server center for enhanced data processing and task execution. CareBot, equipped with various sensors and manipulators, improves task execution independently or with the sensor network. The server center uses an ontology-based approach and an optimized genetic algorithm for efficient task planning and emergency response. Compared to systems like the Gator Tech Smart House, CBASH excels in combining monitoring with proactive task execution, effectively managing daily activities and emergencies. This system significantly advances smart home automation, offering a robust solution for aging in place and potential for further AI integration and broader applications.

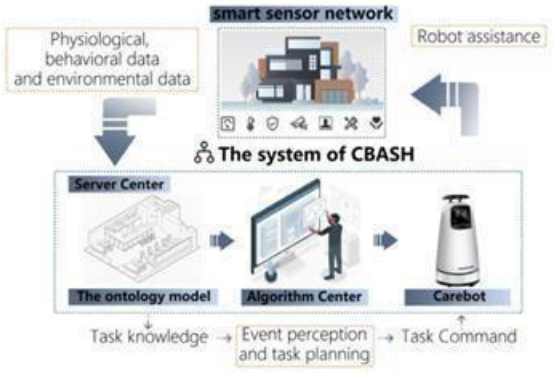

Figure 5. CBASH System Overview

III. Methodology

This section presents the methodology that we are used to achieve the objectives of the review. The stages of our methodology include:

(1). Planning
(2). Search Strategy
(3). Selection Process
(4). Quality Assessment
(5). Data Collection
(6). Data Analysis

The purpose of this systematic review is to explore and analyze smart home automation technologies based on IoT. During the planning phase, we identified the steps necessary for us to accomplish the objectives of the current study. This review aims to identify the current state of these technologies, assess their energy effectiveness, and highlight security mechanism in smart home automation.

In the Search strategy phase to find relevant papers, we used databases and sources such as IEEE Xplore, Google Scholar, Elsevier and MDPI. We used keywords and phrases like Internet of Things, Smart Home, Home Automation Technologies etc. In the Selection phase we screened papers by reviewing their titles and abstracts to determine their relevance to the topic. Also, we referred to the latest review papers published from 2017 to 2024. Out of 285 papers, we initially selected twenty-three papers for primary studies.

We assessed the quality and reliability of the papers using criteria such as methodological rigor, relevance to IoT in smart homes, and the impact of the findings. Each paper was systematically evaluated to ensure it met these standards, allowing us to identify and mitigate any potential biases. This comprehensive approach ensured that only high-quality and relevant studies were included in the review, providing a robust foundation for our analysis of smart home automation technologies. From each paper, we extracted data on the methodologies used, the technologies discussed, the results obtained, and the conclusions drawn. In the Data analysis phase, the review revealed key insights into the current state of smart home automation technologies, highlighting their benefits and challenges.

Iv. Results & Analysis

This review shows that IoT-based smart home automation has advanced significantly in energy efficiency, security, and convenience, yet faces critical challenges. Energy management methods like Intrusive Load Monitoring (ILM) and Non-Intrusive Load Monitoring (NILM) have achieved 90% and 70% accuracy, respectively, but balancing precision and cost remains challenging. Heterogeneous Energy Harvesting (IHEH) is efficient, converting up to 90% of waste energy; however, only 40% of studies integrate decentralized renewables, limiting scalability.

Anomaly detection models, particularly those using machine learning, demonstrate over 90% accuracy, though rare-event detection requires large datasets, which are often unavailable. Federated learning offers a promising privacy-preserving approach but appears in only 30% of studies. Privacy remains a core issue, with about 50% of systems relying on data anonymization, which can still risk re-identification.

Security in smart homes relies on secure protocols (ZigBee, LoRaWAN, etc.), yet 40% face compatibility issues across devices. Blockchain, examined in 55% of studies, shows potential to secure data with 70% resilience against cyber threats, but scalability challenges limit adoption. Network architecture and authentication techniques like Temporal Identities and JSON Web Tokens (JWT) achieve 80% data integrity, though only 45% are tailored for IoT compatibility.

Assistive technologies, especially for elderly users, offer task execution accuracy of 85% and appliance recognition accuracy of 90% but face challenges with data imbalance and feature optimization. Predictive maintenance and health monitoring, addressed by only 25% of studies, present growth opportunities.

Overall, 60% of studies highlight limitations in scalability, privacy, and standardization, suggesting the need for hybrid energy management, privacy-preserving anomaly detection, and adaptable security frameworks. Future improvements in these areas will make IoT-enabled smart homes more resilient, secure, and user-centric, promoting wider adoption and functionality in diverse settings.

IV. Discussion

The evaluation of IoT-based smart home automation highlights notable advancements in enhancing comfort, security, and energy efficiency. Despite this progress, critical gaps remain in the interoperability, scalability, and methodological rigor of current research. Many studies lack standardized research protocols, raising concerns about the reliability and replicability of findings. Establishing these standards is essential to support the consistent and reliable development of IoT solutions in smart home environments.

From a technical perspective, energy management is an area of both progress and challenge. Techniques such as Intrusive Load Monitoring (ILM) and Non-Intrusive Load Monitoring (NILM) have increased energy efficiency, but each presents trade-offs in cost and accuracy. Developing adaptable hybrid models that balance these aspects remains a gap in the field. Similarly, Heterogeneous Energy Harvesting (IHEH) techniques have demonstrated up to 90% efficiency in energy conversion, yet limited integration with decentralized renewable sources constrains scalability. Future solutions should prioritize adaptive, real-time energy management systems that address both sustainability and cybersecurity risks associated with IoT connectivity.

Anomaly detection using machine learning techniques has achieved high accuracy, though rare-event detection remains a challenge due to insufficient training data. Privacy-preserving methods, such as federated learning, show potential to enhance data security without centralizing user data, yet are only applied in a minority of studies. Advanced models like the Harmony-Enhanced Extra Trees (HEET) model improve threat detection, but balancing accuracy with user privacy requires more exploration.

Security mechanisms are essential in IoT-enabled smart homes, where the diversity of devices and protocols demands robust solutions. Although protocols like ZigBee and LoRaWAN reduce unauthorized access, compatibility issues across devices signal a need for standardization. Blockchain offers decentralized security, yet scalability limitations in high-frequency data environments restrict its broader application.

The architecture and authentication of IoT networks must evolve to support expanding smart home ecosystems. Current technologies like LoRa and ECC enhance connectivity, but integration with adaptive, IoT-specific verification techniques is needed. Lastly, assistive technologies are emerging as valuable tools for elderly care but face challenges in predictive maintenance and health monitoring.

In summary, addressing these gaps through rigorous methodologies, privacy-preserving anomaly detection, and scalable security frameworks will promote resilience, effectiveness, and wider adoption of IoT in smart home automation, ultimately enhancing quality of life in residential settings.

V. Conclusion

The evaluation of IoT-based smart home automation highlights advancements in comfort, security, and energy efficiency, but critical gaps remain in interoperability, scalability, and methodological rigor. Many studies lack standardized protocols, raising concerns about reliability and replicability. Energy management techniques, such as Intrusive Load Monitoring (ILM) and Non-Intrusive Load Monitoring (NILM), demonstrate trade-offs in cost and accuracy, necessitating adaptable hybrid models. Anomaly detection via machine learning shows promise, yet challenges persist in rare-event detection and the application of privacy-preserving methods like federated learning. Security mechanisms must evolve, as existing protocols like ZigBee and LoRaWAN face compatibility issues, underscoring the need for standardization. Additionally, assistive technologies for elderly care present challenges in predictive maintenance. Addressing these gaps through rigorous methodologies and scalable security frameworks is essential for enhancing the resilience and effectiveness of IoT in smart home automation, ultimately improving the quality of life in residential settings.

References

[1] J. H. Kim, “A Survey of IoT Security: Risks, Requirements, Trends, and Key Technologies,” *J. Ind. Intg. Mgmt.*, vol. 02, no. 02, p. 1750008, Jun. 2017, doi: 10.1142/S2424862217500087.

[2] M. Aboubakar, M. Kellil, and P. Roux, “A review of IoT network management: Current status and perspectives,” *Journal of King Saud University - Computer and Information Sciences*, vol. 34, no. 7, pp. 4163–4176, Jul. 2022, doi: 10.1016/j.jksuci.2021.03.006.

[3] J. Wang, M. K. Lim, C. Wang, and M.-L. Tseng, “The evolution of the Internet of Things (IoT) over the past 20 years,” *Computers & Industrial Engineering*, vol. 155, p. 107174, May 2021, doi: 10.1016/j.cie.2021.107174.

[4] J. S. Yalli, M. H. Hasan, and A. Badawi, “Internet Of Things (IOT): Origin, Embedded Technologies, Smart Applications and its Growth in the Last Decade,” *IEEE Access*, pp. 1–1, 2024, doi: 10.1109/ACCESS.2024.3418995.

[5] J. H. Kim, “A Survey of IoT Security: Risks, Requirements, Trends, and Key Technologies,” *J. Ind. Intg. Mgmt.*, vol. 02, no. 02, p. 1750008, Jun. 2017, doi: 10.1142/S2424862217500087.

[6] M. Aboubakar, M. Kellil, and P. Roux, “A review of IoT network management: Current status and perspectives,” *Journal of King Saud University - Computer and Information Sciences*, vol. 34, no. 7, pp. 4163–4176, Jul. 2022, doi: 10.1016/j.jksuci.2021.03.006.

[7] J. Wang, M. K. Lim, C. Wang, and M.-L. Tseng, “The evolution of the Internet of Things (IoT) over the past 20 years,” *Computers & Industrial Engineering*, vol. 155, p. 107174, May 2021, doi: 10.1016/j.cie.2021.107174.

[8] J. S. Yalli, M. H. Hasan, and A. Badawi, “Internet Of Things (IOT): Origin, Embedded Technologies, Smart Applications and its Growth in the Last Decade,” *IEEE Access*, pp. 1–1, 2024, doi: 10.1109/ACCESS.2024.3418995.

[9] K. Maswadi, N. B. A. Ghani, and S. B. Hamid, “Systematic Literature Review of Smart Home Monitoring Technologies Based on IoT for the Elderly,” *IEEE Access*, vol. 8, pp. 92244–92261, 2020, doi:

10.1109/ACCESS.2020.2992727.
[10] A. Zielonka, M. Wozniak, S. Garg, G. Kaddoum, Md. J. Piran, and G. Muhammad, "Smart Homes: How Much Will They Support Us? A Research on Recent Trends and Advances," *IEEE Access*, vol. 9, pp. 26388–26419, 2021, doi: 10.1109/ACCESS.2021.3054575.
[11] P. Franco, J. M. Martinez, Y.-C. Kim, and M. A. Ahmed, "IoT Based Approach for Load Monitoring and Activity Recognition in Smart Homes," *IEEE Access*, vol. 9, pp. 45325–45339, 2021, doi: 10.1109/ACCESS.2021.3067029.
[12] J. Bharathi Madavarapu, H. Islam, A. Appathurai, G. Ali Safdar, N. Muthukumaran, and J. Gnanamalar, "Heterogeneous Energy Harvesting Techniques for Smart Home IoT Acceleration," *IEEE Access*, vol. 12, pp. 73667–73675, 2024, doi: 10.1109/ACCESS.2024.3397664.
[13] S. M. A. A. Abir, A. Anwar, J. Choi, and A. S. M. Kayes, "IoT-Enabled Smart Energy Grid: Applications and Challenges," *IEEE Access*, vol. 9, pp. 50961–50981, 2021, doi: 10.1109/ACCESS.2021.3067331.
[14] M. Yamauchi, Y. Ohsita, M. Murata, K. Ueda, and Y. Kato, "Anomaly Detection in Smart Home Operation From User Behaviors and Home Conditions," *IEEE Trans. Consumer Electron.*, vol. 66, no. 2, pp. 183–192, May 2020, doi: 10.1109/TCE.2020.2981636.
[15] H. Jung Jin, F. Rahimi Ghashghaei, N. Elmrabit, Y. Ahmed, and M. Yousefi, "Enhancing Sniffing Detection in IoT Home Wi-Fi Networks: An Ensemble Learning Approach With Network Monitoring System (NMS)," *IEEE Access*, vol. 12, pp. 86840–86853, 2024, doi: 10.1109/ACCESS.2024.3416095.
[16] M. Yamauchi, Y. Ohsita, and M. Murata, "Platform Utilizing Similar Users' Data to Detect Anomalous Operation of Home IoT Without Sharing Private Information," *IEEE Access*, vol. 9, pp. 130615–130626, 2021, doi: 10.1109/ACCESS.2021.3112482.
[17] A. Abdusalomov, D. Kilichev, R. Nasimov, I. Rakhmatullayev, and Y. I. Cho, "Optimizing Smart Home Intrusion Detection with Harmony-Enhanced Extra Trees," *IEEE Access*, pp. 1–1, 2024, doi: 10.1109/ACCESS.2024.3422999.
[18] J. Yang and L. Sun, "A Comprehensive Survey of Security Issues of Smart Home System: 'Spear' and 'Shields,' Theory and Practice," *IEEE Access*, vol. 10, pp. 124167–124192, 2022, doi: 10.1109/ACCESS.2022.3224806.
[19] Aldahmani, B. Ouni, T. Lestable, and M. Debbah, "Cyber-Security of Embedded IoTs in Smart Homes: Challenges, Requirements, Countermeasures, and Trends," IEEE Open J. Veh. Technol., vol. 4, pp. 281– 292, 2023, doi: 10.1109/OJVT.2023.3234069.
[20] R. Alasmari and A. A. Alhogail, "Protecting Smart-Home IoT Devices From MQTT Attacks: An Empirical Study of ML-Based IDS," IEEE Access, vol. 12, pp. 25993– 26004, 2024, doi: 10.1109/ACCESS.2024.3367113.
[21] S. Arif, M. A. Khan, S. U. Rehman, M. A. Kabir, and M. Imran, "Investigating Smart Home Security: Is Blockchain the Answer?," IEEE Access, vol. 8, pp. 117802–117816, 2020, doi: 10.1109/ACCESS.2020.3004662.
[22] A. Qashlan, P. Nanda, X. He, and M. Mohanty, "Privacy-Preserving Mechanism in Smart Home Using Blockchain," IEEE Access, vol. 9, pp. 103651–103669, 2021, doi: 10.1109/ACCESS.2021.3098795.
[23] L. Kane, V. Liu, M. McKague, and G. R. Walker, "Network Architecture and Authentication Scheme for LoRa 2.4 GHz Smart Homes," IEEE Access, vol. 10, pp. 93212–93230, 2022, doi: 10.1109/ACCESS.2022.3203387.
[24] K. Nimmy, S. Sankaran, K. Achuthan, and P. Calyam, "Lightweight and Privacy-Preserving Remote User Authentication for Smart Homes," IEEE Access, vol. 10, pp. 176–190, 2022, doi: 10.1109/ACCESS.2021.3137175.
[25] E. Simeoni et al., "A Secure and Scalable Smart Home Gateway to Bridge Technology Fragmentation," Sensors, vol. 21, no. 11, p. 3587, May 2021, doi: 10.3390/s21113587.
[26] P. Franco, J. M. Martinez, Y.-C. Kim, and M. A. Ahmed, "A Framework for IoT Based Appliance Recognition in Smart Homes," IEEE Access, vol. 9, pp. 133940–133960, 2021, doi: 10.1109/ACCESS.2021.3116148.
[27] Z. Zhu et al., "CBASH: A CareBot-Assisted Smart Home System Architecture to Support Aging-in-Place," IEEE Access, vol. 11, pp. 33542–33553, 2023, doi: 10.1109/ACCESS.2023.3264272.

A Systematic Literature Review of Weather-Driven Solar Energy Forecasting: Advanced Predictive Analytics

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***Abstract*— The rapid adaptation of renewable energy resources such as solar energy to meet the growing global demand for energy necessitates the accurate and reliable forecasting of energy output to ensure grid stability and efficient resource allocation. In light of this, the topic was chosen to conduct a Systematic Literature Review (SLR) with the aim of gathering knowledge on predictive analytics methodologies, techniques, and approaches to weather-driven solar energy forecasting. The review objectives of ascertaining appropriate predictive analytics techniques significantly used variables, and best evaluation metrics for the same were met by the SLR conducted according to guidelines as proposed by B.Kitchenham [1]. The initial selection of 35 related studies was then narrowed to 15 for further detailed review. The results of the review indicate that Neural Networks (NN), Linear Regression, and Support Vector Machine models are the most used technologies, whereas the most significant variables considered in the studies were solar irradiation, temperature, historical power generation data, and relative humidity. The studies also emphasize the use of evaluation metrics such as RMSE and MAE for validating model accuracy. These findings provide valuable insights into predictive analytics in weather-driven solar energy forecasting and offer recommendations for best-suited approaches such as hybrid predictive models to implement in enhancing the accuracy and reliability of weather-driven solar energy forecasts.**

Keywords*— *Solar energy, weather, forecast, neural networks, machine learning

I. INTRODUCTION

Increasing adaptation of renewable power sources like solar energy into the global energy mix has emphasized the need for precise and reliable forecasting methods[2]. At a time like this with an energy shortage, solar energy is one of the most abundant and most environmentally friendly sources. However, its fundamentally irregular nature poses a huge challenge to grid stability and energy planning[3]. As the demand for sustainable energy grows, the timely endeavour of optimizing solar energy output to meet this demand by utilizing predictive analysis by leveraging weather variables has emerged as a promising solution to enhance the accuracy of solar energy output forecasting[4] whilst maintaining grid stability and efficiency. Despite the many recent advances in solar energy forecasting, there are still a number of unresolved challenges to be tackled in this discipline. Most studies point to a remarkable gap that exists in the design of robust model comparison studies, as ones which would review forecasting accuracy show inconsistency of predictive models across geographic and climatic conditions. Current methods often face challenges such as high variability in weather patterns, regional climatic differences, and the influence of unexpected weather changes on solar irradiance, which complicates accurate energy forecasting. Due to the volatile nature of weather patterns and their geographic variability, a single model rarely achieves consistent accuracy worldwide, and this absence of a single, universally optimal model for different geographic and operational conditions limits forecasting accuracy. This therefore represents a missing link into the practical knowledge needed for industry users to determine which forecasting methods are most appropriate for their local conditions and operation. While machine learning methods promise good solutions, transparency and performance reliabilities of those methods raise a number of questions, particularly on conditions of extreme weather variables that might affect grid stability.

Solar energy forecasting entails utilizing a range of statistical and machine-learning methods to anticipate future solar

power generation[5]. This is achieved by analysing historical power generation data and considering weather factors such as temperature, solar irradiance, and cloud cover[6]. The accuracy of these projections is essential for maximizing the efficiency of solar power plants, enhancing the dependability of the power grid, and providing valuable insights for decision-making in energy trading and resource allocation[7]. This systematic literature review attempts to thoroughly analyse the approaches utilized in predictive analytics for forecasting solar energy output by employing weather factors. Although there has been a growing amount of research conducted in this field, it is necessary to consolidate the existing studies to determine the current patterns, strengths, and weaknesses in the research methods and any possible areas that have not been adequately explored in the literature[8]. This review aims to present a well-organized summary of the current state of research, providing significant insights for academics and practitioners in the field.

The reason for this study arises from the various and quickly progressing prediction models and methodologies suggested in recent years[9]. It is crucial to conduct a methodical investigation of these approaches to comprehend their efficacy, scalability, and suitability in various circumstances. This analysis will enhance the development of more precise and resilient forecasting models by identifying the most promising approaches and emphasizing areas that require additional exploration.

This review will specifically address the following aspects:

- The various categories of predictive models employed for solar energy forecasting encompass statistical methodologies, machine learning algorithms, and hybrid techniques[10].
- The influence and significance of several meteorological factors on the precision of forecasts.
- The techniques for gathering data, preparing it for analysis, and choosing relevant features.
- The evaluation metrics and validation methodologies are used to measure the performance of the model.
- The practical applications and case studies exemplify the tangible efficacy of these models in real-world scenarios[11].

The methodology section will include a comprehensive description of the systematic review process, encompassing the criteria used to choose studies, the tactics employed for conducting searches, and the methodologies utilized for analysing the collected data.

This systematic literature analysis intends to consolidate and critically assess the approaches of predictive analytics for forecasting solar energy output using weather factors. The purpose is to provide information for future studies, improve the accuracy of solar energy projections, and facilitate the effective and sustainable integration of solar power into the energy grid[12].

II. METHODOLOGY

A thorough SLR process was followed to gather knowledge on the methods, techniques, and approaches used in predictive analytics for Solar Energy Output Forecasting. The process guidelines followed were as proposed by [1], adhering to the Guidelines for performing Systematic Literature Reviews in Software Engineering due to the guidelines clarity and conciseness, making them suitable for a systematic review in this field by guaranteeing a fair evaluation of the research topic by using a trustworthy, rigorous, and auditable methodology to further the means of identifying, evaluating, and interpreting all available research relevant to a particular research question, or topic area, or phenomenon of interest.

The three phases of a systematic review; planning, conducting, and reporting were followed as specified in [1] which approach also enhanced the credibility of our findings, ensuring that the review process was both rigorous and accessible to other researchers looking to replicate or expand on this work.

The planning stage included identifying the need for a systematic review, that specific need arose from the requirement to evaluate and draw a general conclusion on the most suitable methods and technologies employed in predictive analytics for solar energy output forecasting to be adopted as predictive modelling techniques and methods for Solar power generation forecasting.

The review protocol was developed to define the rationale for the review and then identify the research questions, search strategy, study selection criteria, and procedures. They are presented as follows.

A. Objectives and Scope

The SLR scope was defined as the research interest of predictive analytics for solar energy output generation forecasting concerning weather conditions. This was done to better consider instances of predictive analytics research relevant to the research topic. Thereafter, the following objectives were defined.

1) Objective 1: To compare different methods and technologies utilized in predictive analytics for solar energy output forecasting.

1) Objective 2: To determine the weather variables most commonly and significantly used in studies on solar energy output forecasting.

1) Objective 3: To assess the evaluation metrics considered in related studies to evaluate model performance and to determine the most accurate and reliable methods to forecast solar energy output.

B. Research Questions

In order to attain the aforementioned objectives, we identified the following Research Questions.

1) Primary Question (PQ): What are the most suitable predictive analytics methods and techniques for forecasting solar energy output based on weather conditions?

2) Secondary Question 01 (SQ1): Which are the weather variables that are most critical in solar energy output forecasting?

3) Secondary Question 02 (SQ2): -What are the best evaluation metrics to assess the performance of predictive models to forecast solar energy output?

C. Search Strategy

Our search strategy was defined as searching for relevant studies in digital libraries such as IEEE Xplore, ACM Digital Library, Science Direct, Emerald Insight, and MDPI. The key phrases 'predictive analytics', 'solar energy', 'weather', and 'machine learning' were mainly sought with query sequences and definitions.

D. Study Selection Strategy

We set the inclusion and exclusion criteria for study selection for the studies considered. By prioritizing studies with robust methodological frameworks and clear use of weather data for forecasting, we aimed to identify the most relevant research for advancing predictive methods in this field, and therefore defined the key inclusion and exclusion criteria as follows.

1) Inclusion Criteria 1 (IC1): studies that propose a model, method, or approach to the specified study.

2) Inclusion Criteria 2 (IC2): studies that include weather variables as a factor in their predictive models, including detailed descriptions of the meteorological variables or datasets and their roles in enhancing forecasting accuracy.

2) Inclusion Criteria 2 (IC2): studies apply predictive analytics or machine learning models specifically to solar energy output forecasting.

1) Exclusion Criteria 1 (EC1): studies published more than a decade ago.

2) Exclusion Criteria 2 (EC2): studies that do not define a method, model, or approach using predictive analytics for solar energy output forecasting.

3) Exclusion Criteria 3 (EC3): studies that have insufficient use of meteorological variables or those that do not clearly specify the details of the methodology and technology applied.

We organized our study selection process into four distinct phases, as described below:

1) Phase 1: As a preliminary selection, we performed the queries, and defined the study group that served for the second phase.

2) Phase 2: Based on the titles, abstracts, and keywords of the preliminary selection studies which were tabulated and examined, we determined and retained 35 relevant studies.

3) Phase 3: Based on the inclusion and exclusion criteria and full reading, we reviewed relevant studies from the previous phase and selected 15 studies from the study group.

4) Phase 4: We re-evaluated and validated the selected studies, with the possibility of inclusion or exclusion of studies.

Table 1. Details of study selection by database

Digital Library	Results
IEEE Xplore	21
ACM	3
Science Direct	8
MDPI	2
Emerald Insight	1
Studies for Phase 2	35

After applying our rigorous screening procedure, 15 studies remained that met all of our criteria and were ultimately included in our review. These studies are: [2] [3] [4] [5] [6] [7] [8] [9] [13] [10] [14] [15] [16] [11] [12].

Furthermore, 20 papers were discarded after an initial review for final evaluation since they did not meet our inclusion criteria or came within exclusion criteria. While those studies have yet to be explicitly retained for work, they provided a good contextual framework. They impacted our perception of the general research area related to solar power forecasting. These studies are:[17] [18] [19] [20] [21] [22] [23] [24] [25] [26] [27] [28] [29] [30] [31] [32] [33] [34] [35] [36].

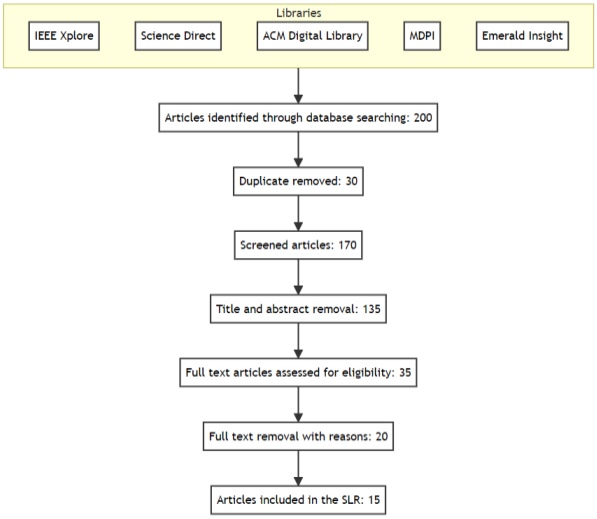

Figure 1. Study selection process details

E. Data Extraction

The data extraction process consisted of summarizing and tabulating information from the selected studies. An Excel workbook was created to extract and synthesize relevant study data in order to answer the research questions as defined in the Systematic Literature Review Protocol.

III. EXPERIMENTAL DESIGN

Due to the fact that the majority of engineering and solar power research is published in IEEE, as well as IEEE's credibility and recognition in the field, we primarily selected

IEEE sources for our experimental design. This made sure that our systematic literature review contained relevant and high-quality studies.

IV. RESULTS

This section summarizes the findings of the systematic literature review, which is focused on general outcomes, techniques and technologies, common factors, and validation methodologies. The report explores research trends and classifies approaches to solar power forecasting that make use of machine learning and statistical methods.

A. General Results

1) Country-wise Distribution: Figure 1 depicts the distribution of countries in which each research study was conducted. Certainly, it can be stated that India and the United States dominated in terms of the number of studies since both countries have poured out numerous papers. Research from India includes studies from Bhubaneswar, Chennai, and Ravet IN. At the same time, studies on the United States include research from Washington DC, Boston MA, and other places. Other contributing countries to the study were Sri Lanka, China, Taiwan, Tunisia, South Korea, and Belgium.

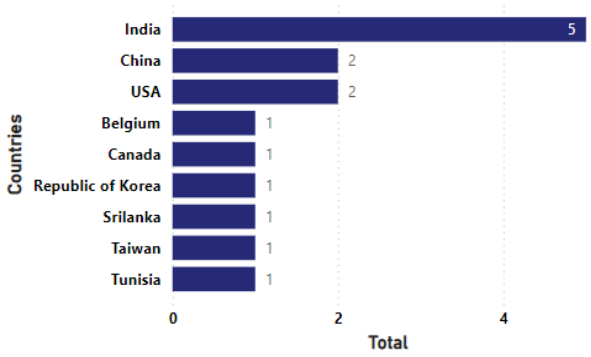

Figure 2. Distribution of studies by countries

2) Type of Publication: Figure 2 depicts the publication vehicles of the selected research. The highest percentage will be that of conference papers, which account for a considerable number of research being published after presentations at conferences. Details are as shown, Conference Papers: 75% 9 studies out of 12, Journal Articles: 25% 3 studies out of 12.

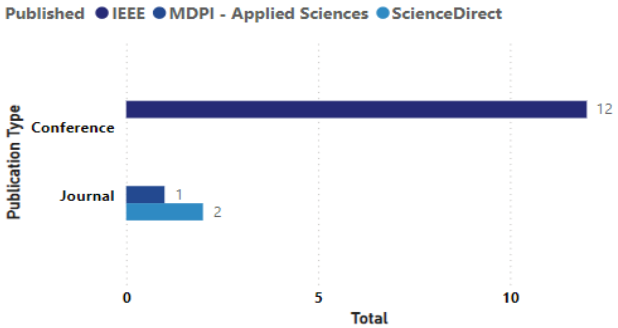

Figure 3. Distribution of studies by publication type

3) Years of Publication: The findings from the research studies were published from 2011 through 2024. The number of these studies concerning their respective published years can be found in Figure 3. Since most of these studies have been published in the last ten years, interest and development in the area of solar power forecasting and related machine learning methods have increased in recent times. 2011–2016: There was a greater focus on core models of machine learning and the first attempts at prediction in earlier studies. 2017–2024: Recent research shows a trend to favour increasingly complex models, such as ensemble techniques and deep learning strategies.

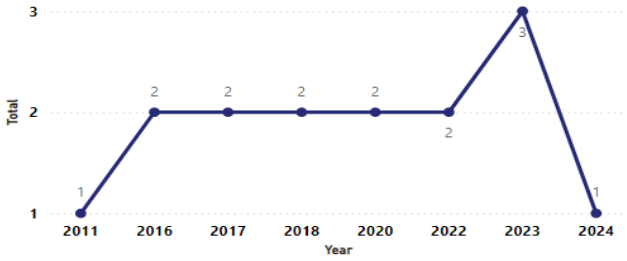

Figure 4. Distribution of studies by year

4) Categorization of Research Approaches: According to the research methods presented by [37] the articles were classified into the following types: validation research, evaluation research, solution proposal, experiment articles, philosophical articles, and opinion articles. The distribution of studies regarding the research approach is represented in Figure 4.

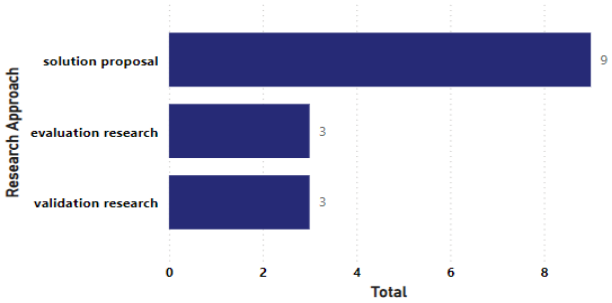

Figure 5. Distribution of studies by research approach

One can identify 9 out of 15 studies that belong to the category of solution proposals. That means most of the research is aimed at providing new solutions based on the types of research methodologies available. The field of solar power forecasting is interested in developing new approaches or models. In contrast, validation and evaluation research is relatively less common, with 3 studies out of 15. This proves that even though new solutions are being constantly put forward, the validation and evaluation of existing models and methods to ensure their correctness and reliability are somewhat overlooked.

B. PQ: What are the most suitable predictive analytics methods and techniques for forecasting solar energy output based on weather conditions?

Methods and technology used varied as seen in the studies selected for analysis. The most used neural networks occurred

in nine research studies. Linear regression topped the list with eight citations, followed by support vector machines used in six types of research. Other important ones were decision trees, random forests, XGBoost, K-Nearest Neighbors, and other ensemble learning models, which also included bagging, boosting, stacking, and voting. Application of these high-end machine learning approaches therefore shows their effectiveness for modelling the most complex and nonlinear correlations characteristic of data in solar power generation. This is evident in studies such as [6] which achieved a high degree of accuracy in their forecasts by using neural networks and SVM, respectively.

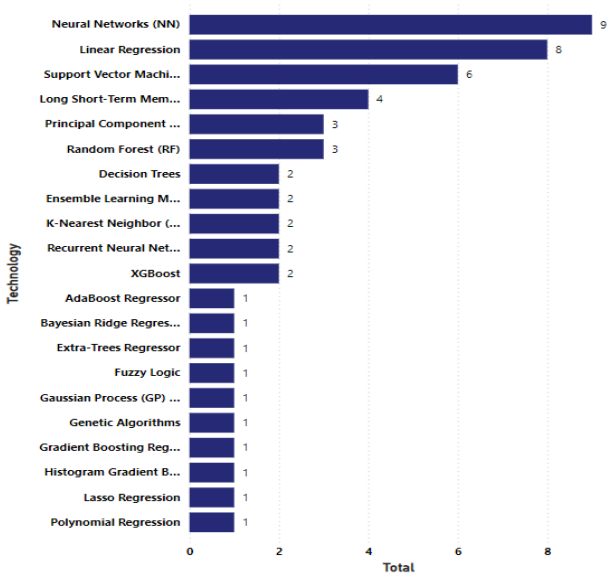

Figure 6. Distribution of technologies that are used

C. SQ1: Which are the weather variables that are most critical in solar energy output forecasting?

Among these studies, we identified most of the frequently used variables in solar power forecasting models. Figure 5 indicates that temperature was the most used variable, appearing in 15 studies; this is then followed by historical power generation data and relative humidity, which are referenced in 12 studies. In turn, the frequency of the remaining variables is wind speed, cloud cover, and solar radiation, underlining their importance in accurate forecasting. These variables are important because they influence solar irradiance directly and, as a result, power output. For example, the paper [9] outlines that for a better forecasting system, complete meteorological data has to be used, including solar radiation, wind speed, etc.

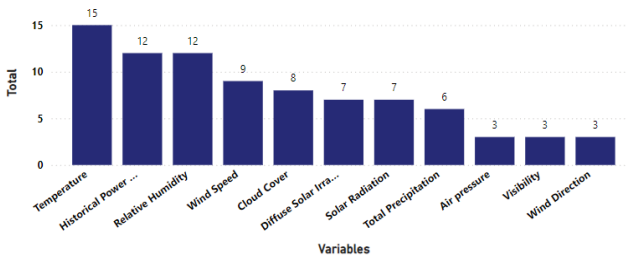

Figure 7. Distribution of variables is used

D. SQ2: What are the best evaluation metrics to assess the performance of predictive models to forecast solar energy output?

To ensure forecasting models are accurate and reliable, various evaluation metrics were employed. Figure 6: The most commonly used were the Root Mean Square Error (RMSE) and the Mean Absolute Error (MAE), used by ten and nine researchers respectively. Others included Mean Bias Error (MBE), R-squared, Mean Absolute Percentage Error(MAPE), and Normalized Root Mean Square Error(NMSE). These measures are important in ascertaining the accuracy of the forecast and the general performance of the models.

Such common validation strategies included cross-validation, comparison with benchmark models, and graphical analysis. For example, in the work [5] performance was measured according to RMSE and MAE for different models, working well with LSTM and XGBoost outperforming classic linear regression approaches.

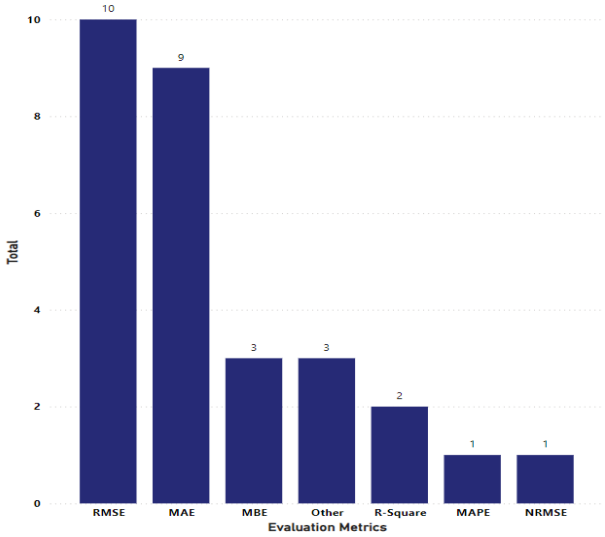

Figure 8. Distribution of evaluation metrics used

V. DISCUSSION

We conducted this review to obtain a general overview of existing research on solar power forecasting. In particular, an attempt was made to find out which approaches and technologies were most effective, which variables were used to generate or validate the models, and which evaluation criteria were used.

A. Recap Research Questions/Objectives

This SLR provides an overview of the methodologies and technologies used for solar power forecasting, classifies them, identifies common variables, and understands the assessment criteria put forth in validating these models.

B. Key Findings

The analysis shows a strong reliance on advanced machine learning techniques, among which neural networks (NN) and support vector machines (SVM) come up most frequently.

These techniques are very effective in managing and making solar power generation predictions. Variables commonly detected were temperature, past power generation data, and relative humidity, underlining their importance in predicting models. Other than that, RMSE and MAE showed up as key evaluation measures, underlining their wide usage in the output of model accuracy.

C. Interpretation and Comparison

The top two models are NN and SVM, meaning machine learning algorithms are getting more interest due to the ability of these techniques to deal with complex, high-dimensional data that is needed to have proper solar power forecasts. Much attention has been paid to temperature and historical power-generating variables, reflecting the importance of the parameters in making solar power generation forecasts. The fact that machine learning algorithms performed better than conventional statistical methods agree quite well with the recent advances or developments in this field, encouraging wider use.

D. Future Research Directions

Future research should aim at developing hybrid models that inherit the advantages of different machine learning algorithms, such as neural networks and ensemble methods. The search for more rigorous validation methodologies needs to be pursued relentlessly, along with the inclusion of other variables likely to influence solar power generation. Researching different geographical and climatic zones will render these models more usable and reliable.

VI. CONCLUSION

A. Recommendations

This systematic literature review has provided a comprehensive analysis of weather-driven solar energy forecasting techniques, focusing on advanced predictive analytics methods. In particular, the review identified machine learning approaches of neural networks and support vector machines that were predominantly used, and further identified temperature, historical power generation data, and relative humidity as the common and significantly considered variables for accurate forecasting. This insight can guide future research in feature collection and data collection strategies. The prevalence of evaluation metrics such as RMSE and MAE highlights the importance of quantitative accuracy measures in assessing model performance.

When considering the implications of this review in future research work, we can identify a significant potential for developing hybrid models that leverage the strengths of multiple machine learning algorithms. Future research should also focus on more rigorous validation methodologies and the inclusion of a broader range of influential variables. Additionally, expanding studies to diverse geographical and climatic zones would enhance the generalizability and reliability of predictive models.

REFERENCES

[1] B. Kitchenham, “Procedures for Performing Systematic Reviews,” *Keele, UK, Keele Univ.*, vol. 33, Aug. 2004.

[2] D. Solanki, U. Upadhyay, S. Patel, R. Chauhan, and S. Desai, “Solar Energy Prediction using Meteorological Variables,” in *2018 International Conference on Recent Innovations in Electrical, Electronics & Communication Engineering (ICRIEECE)*, Bhubaneswar, India: IEEE, Jul. 2018, pp. 16–19. doi: 10.1109/ICRIEECE44171.2018.9009175.

[3] Y.-J. Zhong and Y.-K. Wu, “Short-Term Solar Power Forecasts Considering Various Weather Variables,” in *2020 International Symposium on Computer, Consumer and Control (IS3C)*, Taichung City, Taiwan: IEEE, Nov. 2020, pp. 432–435. doi: 10.1109/IS3C50286.2020.00117.

[4] J. K. Pandey, “Prediction for Solar Energy Different Climatic Conditions to Harvest Maximum Energy,” in *2023 International Conference on Networking and Communications (ICNWC)*, Chennai, India: IEEE, Apr. 2023, pp. 1–6. doi: 10.1109/ICNWC57852.2023.10127523.

[5] O. Bamisile, C. J. Ejiyi, E. Osei-Mensah, I. A. Chikwendu, J. Li, and Q. Huang, “Long-Term Prediction of Solar Radiation Using XGboost, LSTM, and Machine Learning Algorithms,” in *2022 4th Asia Energy and Electrical Engineering Symposium (AEEES)*, Chengdu, China: IEEE, Mar. 2022, pp. 214–218. doi: 10.1109/AEEES54426.2022.9759719.

[6] P. A. G. M. Amarasinghe and S. K. Abeygunawardane, “Application of Machine Learning Algorithms for Solar Power Forecasting in Sri Lanka,” in *2018 2nd International Conference On Electrical Engineering (EECon)*, Colombo: IEEE, Sep. 2018, pp. 87–92. doi: 10.1109/EECon.2018.8541017.

[7] A. Alfadda, R. Adhikari, M. Kuzlu, and S. Rahman, “Hour-ahead solar PV power forecasting using SVR based approach,” in *2017 IEEE Power & Energy Society Innovative Smart Grid Technologies Conference (ISGT)*, Washington, DC, USA: IEEE, Apr. 2017, pp. 1–5. doi: 10.1109/ISGT.2017.8086020.

[8] N. Son and M. Jung, “Analysis of Meteorological Factor Multivariate Models for Medium- and Long-Term Photovoltaic Solar Power Forecasting Using Long Short-Term Memory,” *Applied Sciences*, vol. 11, no. 1, p. 316, Dec. 2020, doi: 10.3390/app11010316.

[9] M. V. Khaire, A. G. Thosar, and V. N. Pande, “Prediction of Solar Power Generation Using NWP and Machine Learning,” in *2023 3rd Asian Conference on Innovation in Technology (ASIANCON)*, Ravet IN, India: IEEE, Aug. 2023, pp. 1–6. doi: 10.1109/ASIANCON58793.2023.10270030.

[10] Jiahui Guo *et al.*, “An ensemble solar power output forecasting model through statistical learning of historical weather dataset,” in *2016 IEEE Power and Energy Society General Meeting (PESGM)*, Boston, MA, USA: IEEE, Jul. 2016, pp. 1–5. doi: 10.1109/PESGM.2016.7741059.

[11] D. Chakraborty, J. Mondal, H. B. Barua, and A. Bhattacharjee, “Computational solar energy – Ensemble learning methods for prediction of solar power generation based on meteorological parameters in Eastern India,” *Renewable Energy Focus*, vol. 44, pp. 277–294, Mar. 2023, doi: 10.1016/j.ref.2023.01.006.

[12] N. Sharma, P. Sharma, D. Irwin, and P. Shenoy, “Predicting solar generation from weather forecasts using machine learning,” in *2011 IEEE International Conference on Smart Grid Communications (SmartGridComm)*, Brussels, Belgium: IEEE, Oct. 2011, pp. 528–533. doi: 10.1109/SmartGridComm.2011.6102379.

[13] S. Diop, P. S. Traore, and M. Lamine Ndiaye, “Power and Solar Energy Predictions Based on Neural Networks and Principal Component Analysis with Meteorological Parameters of Two Different Cities: Case of Diass and Taïba Ndiaye,” in *2022 IEEE International Conference on Electrical Sciences and Technologies in Maghreb (CISTEM)*, Tunis, Tunisia: IEEE, Oct. 2022, pp. 1–6. doi: 10.1109/CISTEM55808.2022.10044065.

[14] M. Rana, I. Koprinska, and V. G. Agelidis, “Solar power forecasting using weather type clustering and ensembles of neural networks,” in *2016 International Joint Conference on Neural Networks (IJCNN)*, Vancouver, BC, Canada: IEEE, Jul. 2016, pp. 4962–4969. doi: 10.1109/IJCNN.2016.7727853.

[15] N. Saxena *et al.*, “Hybrid KNN-SVM machine learning approach for solar power forecasting,” *Environmental Challenges*, vol. 14, p. 100838, Jan. 2024, doi: 10.1016/j.envc.2024.100838.

[16] K. Chen, Z. He, K. Chen, J. Hu, and J. He, “Solar energy forecasting with numerical weather predictions on a grid and convolutional networks,” in *2017 IEEE Conference on Energy Internet and Energy System Integration (EI2)*, Beijing: IEEE, Nov. 2017, pp. 1–5. doi: 10.1109/EI2.2017.8245549.

[17] S. Vyas, S. Bhuwania, S. Mishra, H. Patel, and B. Tripathi, “The Impacts of Maintenance Weather and Aging on Solar Power Generation Forecasting and Prediction,” in *2023 IEEE IAS Global Conference on Renewable Energy and Hydrogen Technologies (GlobConHT)*, Male, Maldives: IEEE, Mar. 2023, pp. 1–6. doi: 10.1109/GlobConHT56829.2023.10087613.

[18] B. S, H. V. U S, and R. B, “Solar Powered Efficient Weather Forecasting Using IOT Technology,” in *2022 1st International Conference on Computational Science and Technology (ICCST)*, CHENNAI, India: IEEE, Nov. 2022, pp. 682–685. doi: 10.1109/ICCST55948.2022.10040461.

[19] S. Tiwari, R. Sabzehgar, and M. Rasouli, “Short Term Solar Irradiance Forecast Using Numerical Weather Prediction (NWP) with Gradient Boost Regression,” in *2018 9th IEEE International Symposium on Power Electronics for Distributed Generation Systems (PEDG)*, Charlotte, NC: IEEE, Jun. 2018, pp. 1–8. doi: 10.1109/PEDG.2018.8447751.

[20] M. Detyniecki, C. Marsala, A. Krishnan, and M. Siegel, “Weather-based solar energy prediction,” in *2012 IEEE International Conference on Fuzzy Systems*, Brisbane, Australia: IEEE, Jun. 2012, pp. 1–7. doi: 10.1109/FUZZ-IEEE.2012.6251145.

[21] H. K. Adli, K. A. K. Husin, N. H. M. Hanafiah, M. A. Remli, F. Ernawan, and P. W. Wirawan, “Forecasting and Analysis of Solar Power Output from Integrated Solar Energy and IoT System,” in *2021 5th International Conference on Informatics and Computational Sciences (ICICoS)*, Semarang, Indonesia: IEEE, Nov. 2021, pp. 222–226. doi: 10.1109/ICICoS53627.2021.9651831.

[22] M. Ueshima, T. Babasaki, K. Yuasa, and I. Omura, “Examination of Correction Method of Long-term Solar Radiation Forecasts of Numerical Weather Prediction,” in *2019 8th International Conference on Renewable Energy Research and Applications (ICRERA)*, Brasov, Romania: IEEE, Nov. 2019, pp. 113–117. doi: 10.1109/ICRERA47325.2019.8997070.

[23] V. Gider, C. Budak, D. Izci, and S. Ekinci, “Daily Solar Radiation Prediction Using LSTM Neural Networks,” in *2022 Global Energy Conference (GEC)*, Batman, Turkey: IEEE, Oct. 2022, pp. 168–172. doi: 10.1109/GEC55014.2022.9987055.

[24] J. M. Filipe, R. J. Bessa, J. Sumaili, R. Tome, and J. N. Sousa, “A hybrid short-term solar power forecasting tool,” in *2015 18th International Conference on Intelligent System Application to Power Systems (ISAP)*, Porto, Portugal: IEEE, Sep. 2015, pp. 1–6. doi: 10.1109/ISAP.2015.7325543.

[25] A. Gensler, J. Henze, B. Sick, and N. Raabe, “Deep Learning for solar power forecasting — An approach using AutoEncoder and LSTM Neural Networks,” in *2016 IEEE International Conference on Systems, Man, and Cybernetics (SMC)*, Budapest, Hungary: IEEE, Oct. 2016, pp. 002858–002865. doi: 10.1109/SMC.2016.7844673.

[26] F. Nicoletti and P. Bevilacqua, “Hourly Photovoltaic Production Prediction Using Numerical Weather Data and Neural Networks for Solar Energy Decision Support,” *Energies*, vol. 17, no. 2, p. 466, Jan. 2024, doi: 10.3390/en17020466.

[27] R. Nageem and J. R, “Predicting the Power Output of a Grid-Connected Solar Panel Using Multi-Input Support Vector Regression,” *Procedia Computer Science*, vol. 115, pp. 723–730, 2017, doi: 10.1016/j.procs.2017.09.143.

[28] C. Brester, V. Kallio-Myers, A. V. Lindfors, M. Kolehmainen, and H. Niska, “Evaluating neural network models in site-specific solar PV forecasting using numerical weather prediction data and weather observations,” *Renewable Energy*, vol. 207, pp. 266–274, May 2023, doi: 10.1016/j.renene.2023.02.130.

[29] S. Pereira, P. Canhoto, and R. Salgado, “Development and assessment of artificial neural network models for direct normal solar irradiance forecasting using operational numerical weather prediction data,” *Energy and AI*, vol. 15, p. 100314, Jan. 2024, doi: 10.1016/j.egyai.2023.100314.

[30] M. Perera, J. De Hoog, K. Bandara, D. Senanayake, and S. Halgamuge, “Day-ahead regional solar power forecasting with hierarchical temporal convolutional neural networks using historical power generation and weather data,” *Applied Energy*, vol. 361, p. 122971, May 2024, doi: 10.1016/j.apenergy.2024.122971.

[31] J. Smagorinsky, “Data processing requirements for the purposes of numerical weather prediction,” in *Papers and discussions presented at the Dec. 8-10, 1953, eastern joint AIEE-IRE computer conference on information processing systems---reliability and requirements - AIEE-IRE ’53 (Eastern)*, Washington, D.C.: ACM Press, 1953, p. 22. doi: 10.1145/1434878.1434885.

[32] J. Klaiber and C. Van Dinther, “Deep Learning for Variable Renewable Energy: A Systematic Review,” *ACM Comput. Surv.*, vol. 56, no. 1, pp. 1–37, Jan. 2024, doi: 10.1145/3586006.

[33] K. Bouchouicha, N. Bailek, A. Razagui, M. EL-Shimy, M. Bellaoui, and N. E. I. Bachari, “Comparison of artificial intelligence and empirical models for energy production estimation of 20 MWp solar photovoltaic plant at the Saharan Medium of Algeria,” *IJESM*, vol. 15, no. 1, pp. 119–138, Jan. 2021, doi: 10.1108/IJESM-12-2019-0017.

[34] C. Zhang, Z. Yan, C. Ma, and X. Xu, “Prediction of Direct Normal Irradiation Based on CNN-LSTM Model,” in *Proceedings of the 2020 5th International Conference on Multimedia Systems and Signal Processing*, Chengdu China: ACM, May 2020, pp. 74–80. doi: 10.1145/3404716.3404719.

[35] C.-H. Lee, H.-C. Yang, and G.-B. Ye, “Predicting the Performance of Solar Power Generation Using Deep Learning Methods,” *Applied Sciences*, vol. 11, no. 15, p. 6887, Jul. 2021, doi: 10.3390/app11156887.

[36] B. O. Abisoye, Y. Sun, and W. Zenghui, “A survey of artificial intelligence methods for renewable energy forecasting: Methodologies and insights,” *Renewable Energy Focus*, vol. 48, p. 100529, Mar. 2024, doi: 10.1016/j.ref.2023.100529.

[37] K. Petersen, R. Feldt, S. Mujtaba, and M. Mattsson, “Systematic Mapping Studies in Software Engineering,” *Proceedings of the 12th International Conference on Evaluation and Assessment in Software Engineering*, vol. 17, Jun. 2008.

The Intelligent Flyer Image Generating System for Event Promotions

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Abstract **- The Intelligent Flyer Image Generating System (Vexel) addresses challenges in traditional flyer design, which often demands substantial time and design expertise. By integrating advanced AI technologies, including a Large Language Model (LLM), Stable Diffusion Model, and Natural Language Processing (NLP), Vexel automates the flyer design process, creating high-quality, professional flyers for event promotions in under one minute without requiring design skills. The development process involved creating an intuitive interface where the LLM converts user-provided tags and color inputs into accurate text prompts, which the Stable Diffusion model uses to generate visually appealing, customized backgrounds aligned with the event theme. NLP techniques assist in predicting optimal flyer layouts by evaluating both text and visual elements, ensuring visually cohesive and appealing designs. This seamless AI collaboration overcomes the limitations of traditional design tools and template-based platforms, offering a fast, user-friendly solution for non-designers and professionals alike. Future plans include improving Vexel's efficiency, adding features for guest speaker details, and expanding its capabilities to other types of marketing materials.**

Keywords - Flyer design, Generative AI, Image processing, LLM, NLP, Stable Diffusion

I. INTRODUCTION

Creating eye-catching flyers is a crucial component of event promotion, serving as a visual invitation that captures attention and conveys essential information. Designing an effective flyer requires a balance of colors, typography, and layout, traditionally demanding a combination of artistic and design skills. Historically, this has been a manual process handled by skilled graphic designers using complex tools like Adobe Photoshop and CorelDRAW. While these methods are powerful, they are also time-consuming and costly, requiring significant expertise and access to specialized software. This presents a challenge for individuals or small businesses without the necessary resources or skills to produce professional-quality flyers efficiently.

To address these challenges, Vexel was developed to automate the process using advanced AI technologies. Through a user-friendly interface, users can input key details such as color, tags, headings, content, date, time, venue, and logo. Within one minute, Vexel generates a high-quality, professional flyer, making sophisticated design accessible to users of all skill levels and eliminating the need for specialized design knowledge. This automated process significantly reduces the time and effort required, which is a key motivation behind Vexel's development.

The core objectives guiding Vexel's design and development are as follows.

• LLM and Stable Diffusion Integration: Vexel combines LLMs for generating text prompts from user input color and tags and Stable Diffusion for generating unique, event-aligned flyer backgrounds, ensuring customization and visual relevance.

• Advanced Image Analysis: By using the SIFT algorithm, Vexel enhances flyer backgrounds with a focus on color,

contrast, textures, patterns, and the rule of thirds, ensuring aesthetically pleasing results.

• Layout Selection (Template): NLP techniques predict the optimal flyer layout based on prompts and image analysis results, dynamically adapting to user content for a cohesive design.

• User Data Mapping: Custom algorithms accurately place user-provided details on the flyer according to the layout, ensuring clarity and emphasis for readability and impact.

Traditional flyer design tools such as Adobe Photoshop and Canva, while feature-rich, require significant design expertise and time investment. Many AI-based design platforms rely on fixed templates, which limit customization and fail to dynamically adapt to unique event themes or layouts. Vexel addresses these limitations by using AI-driven models for generating custom backgrounds and predicting suitable layouts, thus offering users a more intuitive, time-efficient solution. Its unique combination of LLM, Stable Diffusion, and NLP technologies allows it to automatically adapt to specific design requirements, eliminating the need for extensive design knowledge.

The methodologies and models selected for Vexel were chosen based on their ability to automate design without compromising quality. The use of LLM and NLP models enables a seamless generation of text-based prompts and information layout, while Stable Diffusion addresses the visual requirements with high-quality, artifact-free images. Traditional tools often pose technical challenges and time limitations, particularly for non-professionals, as noted by Shan et al., who highlight the high design skill and hardware requirements of Photoshop [1]. Chidi et al. similarly observe that while CorelDRAW offers design flexibility, it requires considerable time investment [2]. Vexel aims to overcome these issues by employing methods that eliminate technical barriers, reduce time requirements, and support customization.

Recent advancements in online design tools like Canva and Microsoft Designer have improved accessibility for users. However, despite their drag-and-drop interfaces and extensive libraries, these platforms often require considerable user input and manual adjustments, presenting challenges for users without design expertise. As Alsion et al. discuss, tools like Canva have made strides in accessibility but still necessitate a foundational understanding of layout and design principles [3]. Vexel addresses these limitations by fully automating flyer generation with minimal user input, making professional design accessible even for those without a background in design.

With recent advancements in AI, particularly in LLM and NLP integration, new possibilities have emerged for automated design. Kensuke et al. evaluated models like ChatGPT-4, Mistral 8x7B, and Google Gemini, showcasing the potential of these LLMs to replicate human-like cognition in text generation [4]. This capability allows Vexel to interpret user inputs dynamically, enhancing customization and efficiency in flyer design. In image generation, GANs and Stable Diffusion models have evolved as popular options. Introduced by Goodfellow et al., GANs are widely used in applications such as image synthesis, although their limitations in stability have been noted [5].

In contrast, Stable Diffusion Models, which prioritize stability and reliability, produce higher-quality images with minimal artifacts. Rombach et al. demonstrated that Latent Diffusion Models (LDMs) achieve state-of-the-art performance in tasks, [6] such as image inpainting, class-conditional image synthesis, and text-to-image synthesis, making them a fitting choice for Vexel's image generation capabilities.

II. METHODOLOGY

Vexel is a combination of advanced AI models and an intuitive user interface. To implement Vexel, we used high-performance computers with powerful GPUs for intensive tasks. The development environment was set up on Windows, Visual Studio Code served as the IDE and pip and Conda managed Python dependencies. Virtual environments ensured isolated project dependencies. GitHub was used for version control. Figma helped design the high-fidelity prototype. The frontend was built with HTML, CSS, JavaScript, and React. Python with FastAPI was used for the backend, and Firebase handled user authentication. OpenCV and Pillow were used for image processing and manipulation. NLTK and E5-large were fine-tuned for NLP model development. NLP algorithms predicted flyer layouts. GPT-4o generated text prompts, Stable Diffusion created images, and SIFT analysed images. Figure 01 shows the overall design of our system architecture.

GPT-4o was used as the LLM to generate accurate prompts based on user input like event tags and colors. The LangChain template was created to pass these variables, allowing LangChain to facilitate communication between user inputs and the LLM. LangChain templates are the easiest and fastest way to build a production-ready LLM application.

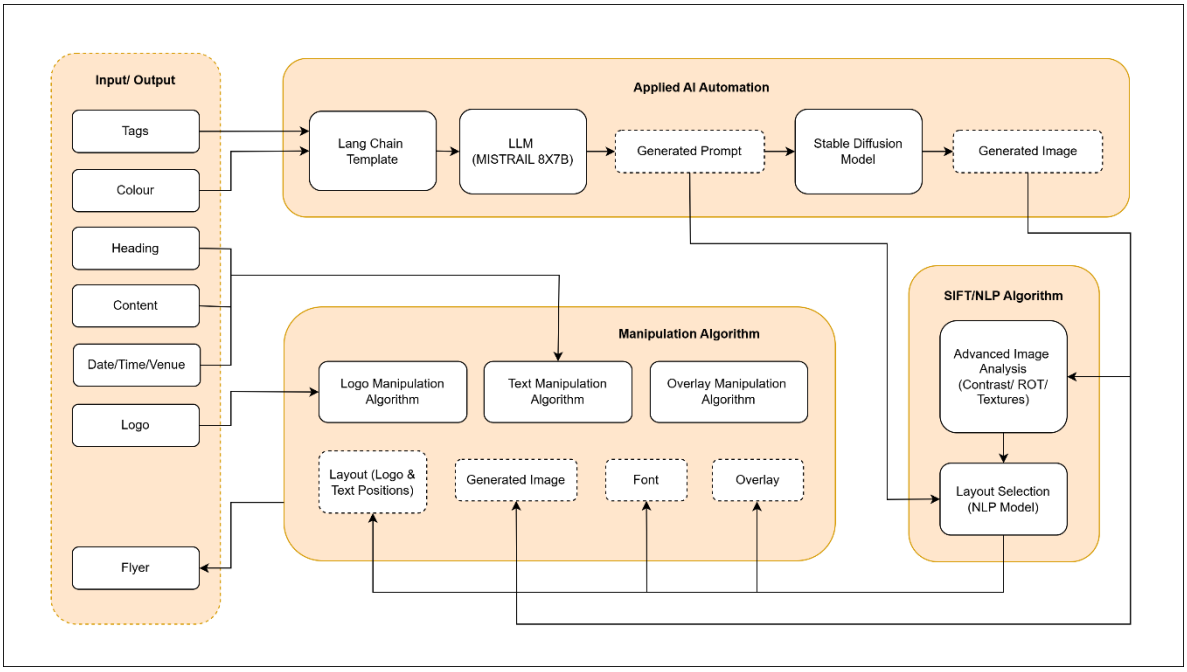

Fig. 1. System Architecture

The Llama Index, which focuses on building RAG systems, was also tried, but LangChain's flexibility made it a better fit. Retrieval-augmented generation (RAG) enhances LLM applications by utilizing custom data to improve response accuracy. During testing, GPT-4 was compared with models like ChatGPT-2, Mistral 8X7B, and Llama3 Meta-Instruct, and GPT-4o was chosen for its capabilities, as some other models were either subscription-based or less capable.

Langchain_template = "Design a background image tailored to an event, using a specified color {color_json} and using thematic visuals according to {tags_json}, please give me a specific prompt to pass the stable diffusion model. Start prompt as 'Prompt:'"

For image generation, we evaluated two options: GANs like DALLE-2 and Midjourney, which are paid, and the free Stable Diffusion Model, which can all be accessed, downloaded, and fine-tuned. DALLE-2 offers more realism due to its generator and validator, but this wasn't needed for flyer creation. The Stable Diffusion XL model was chosen because it had a more stable training process and produced high-quality, diverse samples better suited to the needs.

During image analysis, algorithms like BRISK, ORB, SIFT, and Harris Corner Detection were tried to assess contrast, color, the rule of thirds, and texture. The SIFT algorithm in OpenCV was the most effective for detecting and matching features across different views, performing well even with changes in scale, rotation, and lighting. Despite being more complex to compute, SIFT's versatility makes it ideal for tasks like object recognition, image stitching, and 3D reconstruction. So, we used SIFT for the flyer background image analysis.

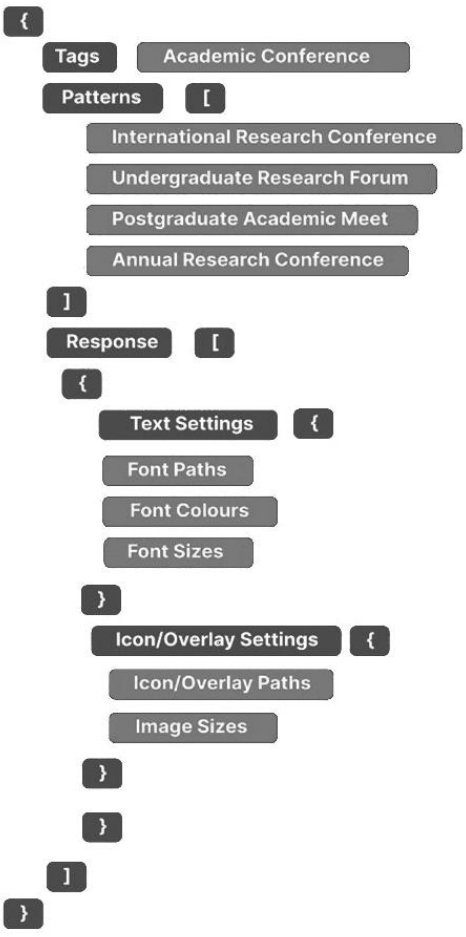

Fig. 2. JSON Dataset Architecture

An NLP algorithm was developed to predict the best design template using a custom JSON dataset with parameters like fonts, colors, overlay paths, and image plotting information. Expert knowledge and additional resources were leveraged to enhance the approach. A tag was added to identify the event type, along with a pattern for identifying events under each event type. Initially, the Word2Vec model was used, but a more advanced semantic search method was needed to match user inputs with the dataset. After experimenting with sentence transformers and the E5 Large model, semantic search was found to outperform keyword matching. As a result, the E5 Large model was chosen and fine-tuned for the specific task.

An image manipulation algorithm was developed using the OpenCV and Pillow libraries. OpenCV handled advanced image processing, while Pillow was used for resizing and merging images like logos. Various mathematical techniques were applied to accurately position fonts and logos. With OpenCV and Pillow, tasks such as image resizing, feature detection, image and text manipulation, and overlay adjustments were performed.

To ensure the robustness of the methods, rigorous validation and evaluation were conducted. This involved split testing of data into training and validation sets to assess the generalizability of the AI models, measuring performance through accuracy, precision, recall, and F1 score. Although most models were pre-trained, localized testing of the custom NLP model was performed. Detailed error analysis was conducted to address issues in model predictions and backend configurations, with a step-by-step examination of each pipeline to identify potential faults. Usage analytics tools were implemented to monitor user interactions and behaviours in real time, while structured usability testing provided insights into real-world performance. Feedback from domain experts in AI, design, and user experience was collected to ensure the system met industry standards.

III. RESULTS

To evaluate Vexel's performance, we compared it with traditional flyer design tools like Adobe Photoshop and Canva. Our study measured time efficiency, design quality, and user satisfaction. Vexel achieved an average design time of under one minute, compared to approximately 10–15 minutes for users with intermediate skills in Photoshop and Canva. However, Vexel's design customization capabilities are currently more limited than those of Photoshop, where experienced users have full control over visual elements.

A. Prompt Generation

Vexel used the LLM (GPT-4o) to generate coherent and contextually relevant prompts for the flyer background.

TABLE I

USER INPUTS	GENERATED PROMPT
TAGGINGS: (CLASSICAL, MELODIES, MUSIC, FESTIVAL, VIBES, COLORFUL) **CLOUR:** (#001F3F)	Prompt: "Create an enchanting background image that embodies the essence of a grand musical celebration. The image should be steeped in the deep, rich hue of #001f3f, serving as the canvas for a symphony of classical elegance and festive cheer. Imagine an orchestra of instruments, from violins to trumpets, each adorned with colorful, vibrant accents that dance in harmony with the music's rhythm. Intertwine elements of classical architecture, like elegant columns and arches, to frame the scene, adding a touch of timeless beauty. The overall atmosphere should be alive with the melodies of celebration, inviting viewers into a world where music and color create an unforgettable vibe. Ensure the composition is balanced, with a focus on creating a visually stunning piece that captures the joy and sophistication of a festive musical event."

[a.] Result of prompt generation according to given user inputs.

As shown in TABLE I, shows how the LLM effectively translates user inputs into detailed, imaginative, and relevant prompts. Users were highly satisfied with the generated text, which significantly reduced the time and effort needed to brainstorm design ideas. This capability made the design process more efficient and user-friendly.

B. Image Generation

The Diffusion Model successfully generated high-quality images that matched user specifications. Users gave positive feedback on the relevance and quality of these images. TABLE II shows that the generated images included detailed elements and vibrant colors, meeting the desired aesthetic and thematic requirements. This demonstrates the Diffusion Model's effectiveness in image creation.

TABLE I I

INPUTS	GENERATED IMAGE
TAGGINGS: (CLASSICAL, MELODIES, MUSIC, FESTIVAL, VIBES, COLORFUL) **CLOUR:** (#001F3F)	

[b.] Result of image generation according to the generated prompt.

C. Background Image Analysis

Fig. 3. Image Analysis Output and Results

Vexel's background image analysis, powered by the Scale-Invariant Feature Transform (SIFT) algorithm, provided in-depth insights into the visual characteristics of the generated images. This analysis covered key metrics, including color accuracy, contrast levels, adherence to the Rule of Thirds, and texture quality. The precision of the SIFT algorithm allowed for a detailed evaluation of image features, ensuring that each element met rigorous quality criteria. The results confirmed that the images not only align with users' aesthetic preferences but also meet important technical standards. By aligning with these standards, the images ensure both visual appeal and technical reliability, leading to consistently high-quality outcomes that enhance the overall effectiveness of the flyers.

D. Layout Prediction

The Natural Language Processing (NLP) model effectively predicted and optimized the layout of flyer elements, resulting in aesthetically pleasing and logically structured designs. The model's ability to analyze and arrange elements ensures that the flyer's layout is visually coherent and well-organized. By incorporating context-aware adjustments, the model adapts layouts to different types of content and design requirements. User feedback confirmed that these layouts effectively communicated the intended message and maintained a clear and engaging presentation. The successful application of the NLP model highlights its ability to balance various flyer elements, ensuring visual coherence and clarity.

E. Usability Testing: User Feedback

Usability testing engaged a group of users from our target audience to evaluate both the ease of use and the quality of the system's output. Participants provided feedback on their experience with the Vexel platform, highlighting its intuitive interface and the high quality of the generated flyers. Overall,

users rated Vexel very positively, noting its effectiveness in facilitating a seamless design process.

F. Time Efficiency

Users reported a dramatic reduction in the time needed to create flyers compared to traditional methods. On average, the

time required to generate a flyer using Vexel was cut by 90%. This significant improvement in time efficiency demonstrates the platform's ability to streamline the flyer creation process, allowing users to produce high-quality designs much more quickly.

The system produces a customized flyer based on the combined inputs from the user and predictions from the AI models. This output integrates the generated textual content, images, and optimized layout to create a professional and polished flyer that meets the user's specifications and preferences. The final flyer output is shown below.

Inputs		Advanced Image Analysis	Output
Heading	Happy Halloween Party	**Dominant Color:** Orange **Colorfulness score:** 64.08028435183776 **Colorfulness level:** High **Contrast level:** Low **Rule of Thirds:** Center **Image Texture:** High	
Content	Fabulous prizes for Best, Scariest, & Funniest Costumes!		
Color	#f57802		
Tags	Pumpkins, Bats, Halloween, Ghosts		
Heading	Annual Sports Meet 2024	**Dominant Color:** Yellow **Colorfulness score:** 76.77062847411834 **Colorfulness level:** High **Contrast level:** Low **Rule of Thirds:** Center **Image Texture:** High	
Content	We Cordially invite you to the Inaugural ceremony.		
Color	#fae505		
Tags	Runners, Awards, Sports Meet		
Heading	Happy Pongal	**Dominant Color:** Brown **Colorfulness score:** 87.35602696647965 **Colorfulness level:** High **Contrast level:** Low **Rule of Thirds:** Center **Image Texture:** High	
Content	Brings good luck to you, success, and happiness.		
Color	#885c4a		
Tags	Carnival, Music, games, Entertainment		

Fig. 3. Image Analysis Output and Results

Fig. 4. Final output of the flyer

IV. DISCUSSION

A. Model Selection and Performance

The research evaluated different AI models for text generation, image creation, and layout prediction, ultimately choosing those that offered the best performance for Vexel. For instance, Stable Diffusion was selected over GANs for image generation due to its ability to produce sharper and more detailed images. Similarly, GPT-4 was chosen over Mistral8x7B and Meta-Llama-3-8B-Instruct for text generation due to its advanced contextual accuracy and reliability.

The choice of LangChain over Llama Index was driven by its superior integration capabilities, ensuring a smooth workflow and efficient data handling. Additionally, the NLP model was preferred over KOR for its robust language processing capabilities, which enhanced the accuracy and relevance of the generated content.

B. User Experience

The positive user feedback during usability testing affirms the effectiveness of Vexel's user-centered design approach. Users appreciated the intuitive interface, which catered to various levels of technical proficiency. Firebase authentication enhances security by managing user data safely. Overall,

these features ensure a smooth and reliable experience, showing Vexel's dedication to providing a high-quality tool for flyer design.

C. Limitations

Vexel has notable successes but also some limitations. Users can generate only one flyer image at a time, ensuring focused processing and high quality. The system supports up to 40 event types, catering to commonly occurring events and maintaining a streamlined experience. Additionally, each user is allowed only one account to ensure security and integrity. These limitations are designed to enhance system performance, manage operational scope, and uphold security standards.

V. CONCLUSION

Vexel significantly advances flyer creation by integrating Large Language Models, Stable Diffusion Models, and Natural Language Processing, streamlining the design process and reducing flyer creation time by 95% while eliminating the need for extensive design expertise. Its strengths lie in generating accurate prompts, high-quality images, and optimized layouts through a user-friendly interface, making professional flyer design more accessible and efficient. However, Vexel currently supports only one flyer at a time, which may limit productivity for users who needing multiple designs. Additionally, its focus on predefined event types may restrict users looking for custom designs for niche events. These limitations highlight areas for future enhancements, particularly in improving scalability and flexibility to further elevate user satisfaction and functionality.

ACKNOWLEDGEMENTS

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REFERENCES

[1] S. Wu, "Application of Graphic Design Based on Image Design Software," Journal of Physics: Conference Series., vol. 1533, p. No. 3, 2020.

[2] C. M. O. E.-N. a. O. E. Uzor, THE APPLICATION OF CORELDRAW SOFTWARE IN THE CREATION OF SIMPLE AND COMPLEX GRAPHIC DESIGNS., 2023.

[3] A. Gehred, "Canva: Resource Review," 2020.

[4] K. a. A. M. Ono, "Evaluating large language models: Chatgpt-4, mistral 8x7b, and google gemini benchmarked against mmlu," 2024.

[5] S. N. E. S. Latifi, "IMAGE GENERATION WITH GANS-BASED TECHNIQUES: ASurvey".

[6] N. e. a. Ruiz, "Dreambooth: Fine tuning text-to-image diffusion models for subject-driven generation," in Proceedings of the IEEE/CVF conference on computer vision and pattern recognition, 2023

Review of Smart Air Pollution Monitoring Systems

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***Abstract*— Air pollution affects our day-to-day activities and quality of life. Continued exposure to environments with poor air quality is a major public health concern in modern society. The level of air quality is reduced and the air is polluted with time by a lot of factors every day. Therefore, monitoring the quality of the air around us has been an essential task. We can use the help of IoT to design a system that can monitor the quality of air in real-time. We can implement this system on a smaller scale, such as in schools and hospitals, or scale it up to monitor air quality across entire cities.**

Keywords— IoT, pollution, air, monitor, e-learning, sensors

I. INTRODUCTION

We can live without food for days, without water for hours, but without air, it can be minutes or even seconds. Since the period of the industrial revolutions, technology has improved at an exponential rate. We all receive benefits from what technology has evolved into today. But have we considered what it cost us to get here? The WHO estimates that: 4.2 million die prematurely every year from outdoor (ambient) air pollution. 3.8 million people die from indoor air pollution, while a total of 7 million die from all sources of air pollution. So, it is clear that this cannot be neglected. Increase in population, making of new factories, industrial emission, wildfires, transportation, open burning of garbage, not disposing of the waste of factories properly are some of the major reasons that the number of deaths is counted in millions per year. This paper reviews the existing research and technological advancements in smart air pollution monitoring Systems, highlighting the effectiveness of current solutions and identifying potential areas for improvement.

With the use of Arduino, IoT and programming we can build systems that can measure the quality of the air in an area in real-time. We can apply them to monitor both indoor and outdoor air quality. The advantage of this method is that we can take steps towards the safety of people if the air quality of an area suddenly drops. Since minutes and even seconds can matter when it comes to these situations.

Vehicle parks, hospitals, mines, chemical/gas factories are some of the places where it can matter the most. Various research has been conducted to find methods for monitoring air quality. This is a report, and a compilation of the best methods suggested to monitor air pollution.

II. EXISTING WORK

Creating a smart air pollution monitoring system can be divided into the following steps.

- automatic measurement of air, water, and soil parameters.
- information collection and primary information processing.
- visualization of information in a way that the user can understand.
- forecasting changes in the surroundings and informing the user about it.
- informing the interested parties if there is a risk to the public.

Below mentioned are examples of already existing smart air pollution monitoring methods.

A. AirQ System

AirQ solution is a concept designed and developed by four students of the Singapore University of Technology and Design. It consists of low-cost sensors and electronic components. The AirQ uses the BME280 sensor for temperature and humidity measurements, and the Plantower PMS3003 (G3) sensor for PM 2.5 and PM10 measurements. Figure 1 shows the prototype designed by the students.

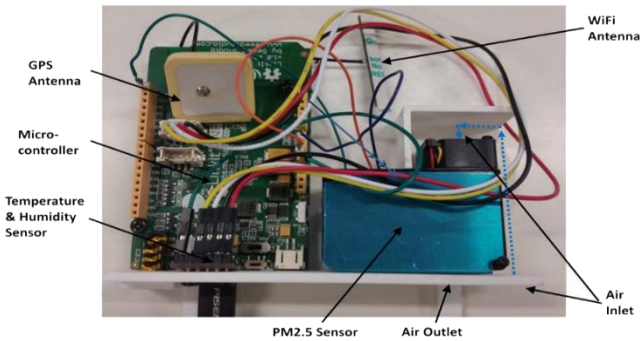

Figure 1. Prototype of AirQ Device

If we want, we can add additional gas sensors to this prototype and monitor other gases such as Carbon Monoxide, Nitrogen Dioxide Carbon Dioxide, etc. This AirQ system should be put in a weather-resistant case and placed in places where we need to monitor the air.

The way this AirQ system works is it collects data about air and uploads it to a cloud-based backend. The device uploads

information in a regular interval such as 30 seconds. The data is stored in MongoDB, which is a NoSQL database. They also have designed a mobile app that shows real-time data and alerts on the data collected by the device. Figure 2 shows an image of the mobile app they developed.

Figure 2. AirQ App Dashboard

Overall, this system is an effective and low-cost design. If sponsored it can be further improved and made into a large-scale product. If supported by governments the AirQ device can be installed in public places such as schools, hospitals, car parks, etc. By doing that we can be aware if something unexpected like a gas leak happens. Overall, this AirQ system is a really impressive invention when it comes to smart air pollution monitoring.

B. *IQAIR.COM*

IQAir is a website that shows air quality details all around the world in real-time. Figure 3 shows a preview of the website and how it sorts out the different parameters.

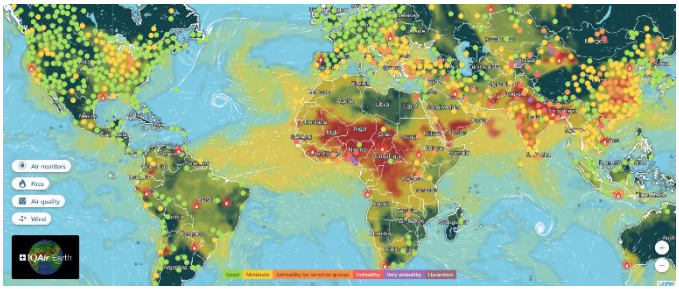

Figure 3. IQAir Global Real-Time Air Quality Monitoring Dashboard

This is a perfect example of a finished smart air pollution monitoring system. It shows data from all over the world. Where the air sensors are planted, where there are fires, where the air quality is worst, how the wind flows etc. For the data analysts, this helps greatly. They can identify patterns and predict the upcoming hazards even. By leveraging advanced data analysis techniques, these systems can also be utilized to forecast potential future hazards associated with air pollution.

III. APPLICATIONS

As mentioned above, the WHO (World Health Organization) estimates 4.2 billion people die per year due to reasons related to air pollution. If we can implement air pollution monitoring systems like the IQAir website in a small area with accurate readings, we can safeguard the health of people.

A. *Factories*

Factories that emit bad chemicals are one of the biggest reasons for environmental pollution. But there also work is done by humans. They could be at a huge risk of exposing themselves to bad gases and chemicals without knowing about that. This is a place where we can apply our air pollution monitoring devices. It can be something similar to the AirQ system. Figure 4 shows the way the devices can be installed in such a way that people get less exposed to hazardous gases.

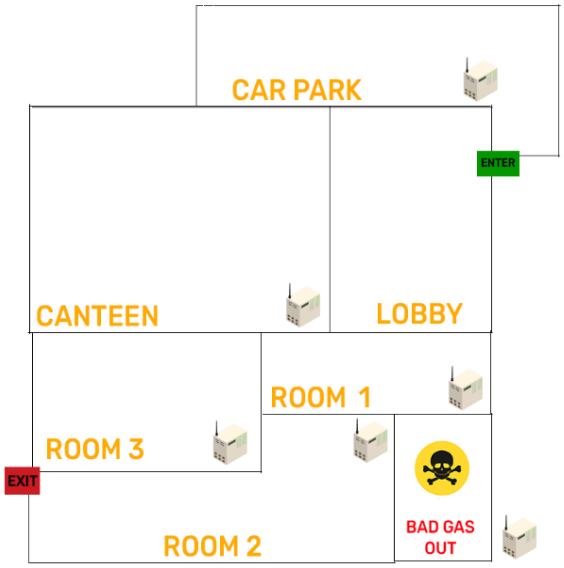

Figure 4. Monitoring devices installation

We can install devices closer to the gas outlet of the gas outlet. If something goes wrong and the hazardous gas is being leaked, we can know for sure. If the gases are leaking slowly, the concentration of the gas increases gradually. Even if the workers get exposed to the gas they can stay fine if the concentration is low. Therefore, we have time for the sensors to detect the gas and alert the workers to evacuate the premises.

B. *Public Places*

In a city, there can be many factories like mentioned above. They can be emitting bad gases into the environment all the time. We can also implant some devices like these in public places around the factories. So if anything goes wrong we can let the public know about it and maybe they can use alternative roads to avoid being exposed to these gases. This method should be applied on a larger scale to places all over

the world if possible. Then we might be able to lessen that death count in big numbers.

IV. HOW TO IMPROVE

Above mentioned systems on 'EXISTING WORK' are 2 great systems for monitoring air pollution. But sometimes we might get into situations where it is not practical to install so many devices. If we want to apply this to a whole city, it can be costly. We cannot install thousands of devices. For that, we can use MoIT. Mobile IoT is an IoT system that can be moved around and reused in different locations. The main advantage of such a MIoT system is that it is economically friendly. As an example, let's say we want to measure the air quality of a city. If we were to install air quality monitoring devices everywhere it could take a lot of time and also a lot of money. If we use a MIoT for that we can easily monitor what we want to monitor with less effort and less cost.

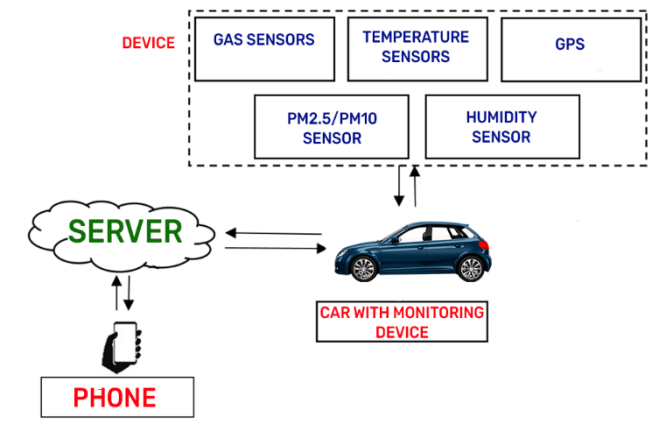

Figure 5. MIoT system

As shown in Figure 5, we can attach air quality monitoring devices to vehicles and collect real-time data of different locations with a single device. With GPS sensors attached to the device itself, we can know the location of the device at the moment and what level of air pollution is being read by the sensors. The use of MIoT is a way we can save both money and more lives. If this kind of device was installed in every car that is made in future, it can be turned into a huge network of monitoring air quality all over the world.

There are many young inventors and researchers who are interested in developing new methods of monitoring air pollution. They have done various research and experiments on smart air pollution monitoring systems. We can find all of them on the internet. But even the countries that are pioneers in technology are also unable to use these methods perfectly. The main reason for that is the use of different platforms. We have good air quality monitoring methods people have already come up with. But most of the time those people are university students who do that research for their academic reasons. If their governments can recognize the potential and sponsor and encourage them to make more of them and mass-produce the devices it would be great.

We have good networks and mobile devices. But there is no interconnection between them. Services like Starlink satellite internet service which provides internet access to the whole globe. In my opinion, we need that kind of network for everything in our lives. If every vehicle can include this air pollution monitoring system into the vehicle's operating system and communicate with other vehicles and make it an own network between them, it would be an ease for us to be aware of the upcoming hazards quickly.

V. CONCLUSION

Air pollution has become one of the biggest problems in today's world. Monitoring it in a smart way offers a powerful way to severe health impacts. With the help of IoT, MIoT, and advanced data analysis, these discussed systems enable proactive responses to hazardous air quality events. While existing solutions such as the AirQ system and IQAir have demonstrated effective models, expanding these systems through approaches like MIoT could provide scalable, cost-effective alternatives for large scale implementations. Integrating air quality sensors with mobile networks, GPS, and global internet services holds great promise for creating interconnected, dynamic systems capable of monitoring and alerting communities to pollution hazards in real time.

In the future, establishing a fully interconnected system for air quality monitoring could greatly enhance our ability to track and respond to pollution events. Such a network, integrating IoT devices with mobile and satellite networks, would allow continuous, large-scale data collection and facilitate real-time alerts across entire regions. This interconnected approach could empower cities and communities to make faster, more informed decisions to mitigate exposure, ultimately leading to a healthier and more sustainable environment.

REFERENCES

[1] G. Spandana and R. Shanmughasundram, "Design and Development of Air Pollution Monitoring System for Smart Cities," *2018*.

[2] V. Choudhary, J. H. T. V. B., and H. B. L., "AirQ: A Smart IoT Platform for Air Quality Monitoring," *2020*.

[3] D. Janeera, H. Poovizhi, S. S. Haseena, and S. Nivetha, "Smart Embedded Framework using Arduino and IoT for Real-Time Noise and Air Pollution Monitoring and Alert System," *2021*.

[4] S. Esfahani, P. Rollins, J. P. Specht, M. Cole, and J. W. Gardner, "Smart City Battery Operated IoT Based Indoor Air Quality Monitoring System," *2020*.

[5] Y. He, A. Kuchansky, S. Paliy, and Y. Shabala, "Problems in Air Quality Monitoring and Assessment," *2021*.

[6] Y. Chen, D. Chen, T. Song, and K. Song, "An Intelligent and Portable Air Pollution Monitoring System Based on Chemical Sensor Array," *2020*.

[7] "AirQ website," *IQAir*, [Online]. Available: https://www.iqair.com/air-quality-map.

Enhanced Cybersecurity: Detecting ARP Spoofing Using Machine Learning Techniques

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***Abstract*—In today's digital world,where digital communication becomes more important, robust cybersecurity measures become more necessary than ever. Address Resolution Protocol (ARP) Spoofing, a subset of Man-in-the-Middle (MitM) attacks gives a significant threat by exploiting vulnerabilities in the Address Resolution Protocol (ARP) to intercept and manipulate data traffic. Traditional methods of detection prove inadequate against such sophisticated attacks. This paper presents a conceptual framework applying machine learning methods to enhance ARP Spoofing attack detection on end-user devices.Approach of the paper considers a range of machine learning models including, Decision Trees, Support Vector Machine (SVM), Random Forest, Neural Networks, and Long Short-Term Memory (LSTM) networks,aiming to achieve high detection accuracy and minimize false positives.The Results are promising for machine learning techniques in enhancing cybersecurity defense and mitigating ARP Spoofing-related risks.**

***Keywords*—ARP Spoofing, Man-in-the-Middle Attacks, Cybersecurity, Machine Learning, Network Security**

I. INTRODUCTION

In today's interconnected digital world, where communication networks serve as the backbone of modern society, the importance of cybersecurity cannot be overstated. The introduction of the internet was able to change the medium of communication, working, and interaction with things around the world.In this new era of interconnectivity, there are lot of security challenges. At the very heart of cybersecurity, there is this very basic fundamental aspect of trust, an almost intangible balance between openness and exposure. The user must have the assurance that the information they are sending through the network will get to the destination as sent-without interception or alteration.

Address Resolution Protocol (ARP) Spoofing attacks, a subset of Man-in-the-Middle (MitM) attacks, present a serious threat by exploiting vulnerabilities within the Address Resolution Protocol (ARP) to secretly intercept and control user's data traffic. In an ARP Spoofing attack, malicious person send falsified ARP messages using a Local Area Network (LAN) to associate their MAC address with the IP address of a legitimate device, thereby intercepting data meant for the legitimate device. Therefore, such incidents can really give a major threat to network security through unauthorized access to the network, data breaches, and violation of user privacy, posing risks across diverse environments, from enterprise networks to dynamic IoT and cloud platforms.

Statistics show the prevalence and harm of ARP Spoofing attacks. A study conducted by the Ponemon Institute found that, man-in-the-middle attacks are among most frequent cybersecurity incidents, with organizations facing an average cost of 2.5 million dollars per breach(1). Attacks against ARP become more frequent and sophisticated due to the advanced growth of network infrastructure. The main objective of this paper is to analyze different machine learning techniques for ARP spoofing detection in end-user devices. This paper addresses the need for adaptable, machine learning based approaches to ARP spoofing detection that can respond to the complexities of modern network enviornments. By conceptually analyzing machine learning techniques such as decision Trees, Support Vector Machine (SVM), Random Forest, Neural Networks, and Long Short-Term Memory (LSTM) networks, this work identifies promising directions for enhancing ARP spoofing defense mechanisms, aiming for high detection accuracy. Since the conventional techniques with static ARP entries and those with ARP detection tools have become inefficient and ineffective in view of the ever-increasing complexity of attack techniques, newer techniques need to be researched and deployed.

The rest of the paper is organized as follows. In section II discuss about background. Section III provides an overview of currently available techniques to deal with ARP attacks. Section IV focus on problem statement and section V describe methodology that based for the paper. Section VI describe the machine learning in cybersecurity and section VII provide details about machine learning for ARP spoofing detection. Section VIII concludes the paper.

II. BAKGROUND

A. How Man-in-the-Middle (MitM) Attack works

A Man-in-the-Middle (MITM) attack is a highly dangerous form of cyber-attack where an adversary intercepts communication between two parties, often without their knowledge. In such an attack, attackers position themselves right between communicating entities, which thereby lets them eavesdrop on the data exchanged. Interception by the attacker lets him gather sensitive information like passwords or emails that were intended for the rightful recipient. Additionally, the attacker

is able to change the data during transportation, which leads to possible misinformation or unauthorized changes. Figure 1 shows how the attacker jumps into the communication stream to get the opportunity to manipulate or steal information before it reaches the destination. The vulnerabilities in network protocols such as ARP or due to a compromised network device may, therefore, result in MITM attacks; hence, stringent measures of intrusion detection and prevention are called for.(2),(3)

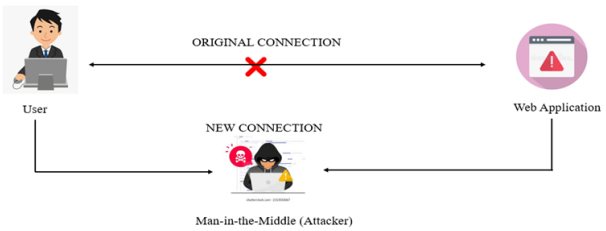

Fig. 1. How Man-in-the-Middle Attack work.

B. How ARP work

Address Resolution Protocol (ARP) is a significant communication protocol used in computer networks to map an IP address to its corresponding MAC (Media Access Control) address (4). The IP address is what is used during logical communication, but the MAC address is what is used in the actual transmission of data. Every device on a network has both an IP address and a MAC address. ARP functions based on an ARP cache, which is stored with the mappings from IP addresses to their corresponding MAC addresses. Before sending data to any other device on the LAN, a device will always check the ARP cache in case the destination MAC address is already stored. If it is, communication continues without ARP. Otherwise, the device broadcasts a request packet onto the network requesting the MAC address of the owner of the target IP address. It broadcasts the request to each device on the LAN, and the one from which it has a matching IP address sends back an ARP reply with its MAC address. Both now update their ARP caches with this new mapping so that communication in the future is allowed (5). How ARP works illustrate by figure 2.

C. How ARP Spoofing work

Despite its simplicity and efficiency, ARP has significant security vulnerabilities due to its stateless and unauthenticated nature. ARP accepts ARP replies without verifying if an ARP request was sent, making it susceptible to ARP spoofing attacks.Through this attack, an attacker sends fake ARP messages linking their MAC address to a legitimate IP address of some other device on the network. This will ensure that data destined for the legitimate device is sent to the attacker instead. It

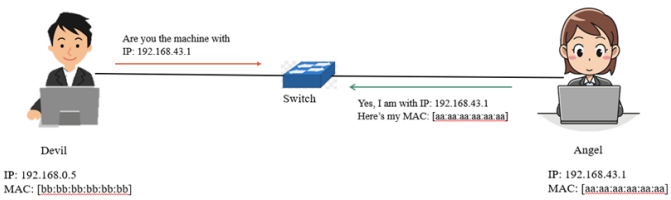

Fig. 2. How Address Resolution Protocol(ARP) work.

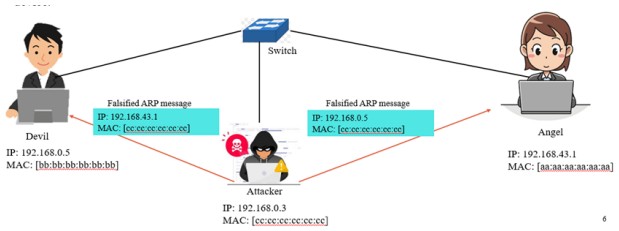

Fig. 3. How ARP Spoofing work.

allows for man-in-the-middle attacks, where the attacker can intercept, alter, or drop the traffic. For instance, an attacker may send ARP packets with fake IP-to-MAC mappings to victim devices; the victims then update their ARP caches with incorrect information. Such manipulation by the attacker may allow him or her to intercept communication between devices, breaching the integrity and confidentiality of data being transferred. Hence, an attacker can enable denial-of-service attacks at the target victim by dropping the intercepted packets, which disrupts communication over the network (1). How ARP spoofing works illustrate by figure 2.

III. Related Work

ARP spoofing has accumulate significant attention in the cybersecurity, especially with emerging technologies such as Internet of Things (IoT). several works have been carried out to investigate different approaches for the detection and mitigation of ARP spoofing attacks.

A. Traditional Detection Tecniques

The paper (1) presents an analysis of various ARP poisoning mitigation techniques emphasized the vulnerabilities of the ARP protocol within LANs. The study shows, within a LAN, ARP messages are used to resolve IP addresses into corresponding MAC addresses. Nevertheless, some of the limitations within this protocol make it rather vulnerable. The two most prominent limitations are the unauthenticated and stateless nature of ARP. So, the attackers can easily exploit these loopholes for their personal gain. Five factors, including flood of spoofed ARP messages, IP exhaustion problem, backward compatibility, single point of failure problem and compatibility with the IP configurations were considered for comparing proposed solutions. The study presented a comparative analysis of different

proposed solutions which are rather popular in the literature and compared different mitigation techniques based on some of the important factors that are considered as limitations to the proposed solutions.This study provide foundational insights into ARP vulnerabilities and they primarily emphasize static solutions, which may lack the adaptability required in today's dynamic network environments.

In another study (5), the researchers have addressed ARP limitations and vulnerabilities, proposing an efficient and secure scheme for ARP poisoning prevention. There are some attacks against ARP like MAC Spoofing, MAC duplicating, Man-in-the-middle (MITM) and denial of services (DOS). In this study, an efficient and secure scheme is proposed to prevent ARP Poisoning. The system has three modules. DHCP IP configuration using DHCP Server, Authentication of the user using radius server + MySQL database, Detection and Prevention of ARP Poisoning. This study demonstrates a utility which gives users the authentication as well as detection and prevention of ARP poisoning in dynamic IP configuration. Performance of the system is good because not use cryptography solutions in their utility. Although this multi faceted approach enhances security, it does not use machine learning, which could adapt to evolving threats more effectively.

Both studies highlight the limitations of traditional techniques in dealing with sophisticated ARP spoofing attacks.

B. Machine Learning Approaches

The study focused on ARP spoofing attacks in IoT networks (6). According to the study, ARP-Spoofing attack is one of the Internet security problems that affects IoT devices that attackers use legitimate ARP packets which traditional detection systems may find it difficult to detect in attacking IoT devices. Therefore, there is a need to have detection systems which use non-traditional approaches in detecting such attacks. This study presents an artificial intelligence method based on neural networks in detecting ARP-Spoofing in IoT networks. This method showed more than 90% accuracy rate in detecting ARP-Spoofing in IoT networks while it was difficult to detect ARP Spoofing with ARIMA statistical method. The proposed approach shows that neural networks can also do anomaly detection in IoT networks. this study highlights the potential of machine learning to improve detection rates in complex environments.

In the paper (7), the authors proposed a machine learning approach for detecting End-Point Man in-the-Middle attacks based on ARP analysis.An attacker can eavesdrop on the communication between two targets and can either perform active or passive monitoring; this affects the confidentiality and integrity of the data flow. This study evaluated the proposed technique using eight linear based ML classification models including Linear SVC, SVC, KNN, Decision Tree, Logistic Regression, Random Forest, Gradient Boosting and Gaussian Naive Bayes. Linear SVC, Gaussian Naïve Bayes, and other models achieved over 99% accuracy in detecting such attacks, introducing a 'stateful' address resolution protocol. For the future works the study suggested exploring how this technique can be implemented in enterprise wired and wireless LANs since the attack scenario used was only based on a single point network.

The paper (8), focuses on predicting ARP spoofing using a deep learning technique called LSTM and common machine learning technique called decision tree. Like many other fields, Machine Learning and Deep Learning can be utilized here to predict the attack early. This research uses 10 Long Short-Term Memory (LSTM) networks and decision tree classifiers to predict ARP Spoofing. The performance of the models is evaluated on a comprehensive dataset that contains data on different sorts of attacks. Results of different experiments showed that both can predict the intrusion quite well. The accuracy achieved by LSTM and decision tree was 99% and 100% respectively, which is better than other solutions. The decision tree beats the complicated LSTM network on execution speed. The study suggests implementing the proposed solution for some other network intrusion datasets as well.

C. Comparative Analysis and Proposed Method

Although these studies provide very valuable insight into traditional and machine learning based ARP spoofing detection, there still remains a gap in integrating these advanced techniques into a framework capable of addressing complexities of modern network environment.This research tries to fill this gap by proposing a adaptive machine learning techniques that improve the efficiency in ARP spoofing detection in variant scenarios, various fields.

IV. PROBLEM STATEMENT

Cybersecurity has become increasingly advanced. Among these, ARP Spoofing, an variant of man-in-the-middle attacks that exploits the vulnerabilities of network protocols for intercepting, changing, and manipulating data traffic. Traditional techniques of detection and mitigation of these advanced attacks have proven quite ineffective and have resulted in huge data breaches, unauthorized access, and privacy violations.

This means there is a need to develop more robust and intelligent security measures against ARP Spoofing, as the existing methods are inadequate in effectively countering this form of attack. Machine learning techniques can learn and adapt to new threats, thus offering a very promising solution for mitigating this challenge. this research aims to evaluate and identify effective machine learning algorithms that can enhance the detection and prevention of ARP spoofing attacks, providing a strong defense in complex cybersecurity world.

V. METHODOLOGY

In this study, take a systematic approach to address the challenges posed by ARP Spoofing in cybersecurity,employing

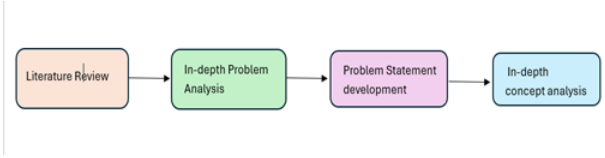

Fig. 4. Methodology steps to identify best Machine Learning techniques.

a structured methodology encompassing literature review, problem analysis, problem statement development, and in-depth concept analysis, particularly focusing on machine learning (ML) applications.The methodology steps are show in figure 4.Literature search begins with a general way to combine the accumulated knowledge and up-to-date developments in the ML field when applied to cybersecurity.This stage includes critical reading of previous published articles, books, and articles to extract information about the earlier methods.After this literature review, a profound analysis of the ARP spoofing problem domain will be pursued for problem analysis and development of the problem statement. From this, a clearly defined problem statement can be developed, with clear major objectives of the problems which the study would intend to address, not limited to improving the accuracy in detection while reducing false positives.

Integrating Machine Learning into Cybersecurity and Detection of ARP Spoofing are findings from the literature review and concept analysis to articulate a clear framework for possible use of ML in cybersecurity, in particular it describes how ARP spoofing be detected. The general implications of, as well as the particular potential benefits, are involved upon from the application of ML to the improvement of detection rates and by adaptive response mechanisms in cybersecurity, in this section.those sections are further describe in the upcoming sections.

VI. MACHINE LEARNING IN CYBERSECURITY

Machine learning (ML) in cyber security is a primarily deals with developing mechanisms for advanced detection, prevention, and response against cyber threats. Similarly, machine learning can also be associated with data mining, computational statistics, and data science. It is related to the development of systems that are capable of learning from past experiences in the form of data. A set of rules, procedures, and functions compose the ML model that will detect interesting patterns in data and identify sequences to predict behavior. These capabilities are very relevant to cybersecurity, where ML can be trained to recognize and classify different forms of cyber-attacks, such as Denial-of-Service (DoS), ARP, network intrusions, and malware detection.

Supervised learning is another principal technique in machine learning that trains models on labeled data to classify or predict outcomes. Techniques like decision trees, k-nearest neighbors (KNN), and support vector machines (SVM) are heavily used in cybersecurity, with tasks such as predicting DoS attacks and different classes of network attacks (2).For example, decision trees and random forests build models placing data into classes based on patterns learned, while SVM builds decision boundaries separating different classes.

Unsupervised learning will further put the discovery of patterns from unlabeled data into practice. Specifically, anomaly detection and discovering hidden patterns to identify cyber threats. Clustering techniques like k-means and hierarchical clustering group similar data points to identify unusual behavior that might indicate a security breach (9).

Deep learning is one of the subfields in ML and is based on artificial neural networks. Those are capable of processing large volumes of complex data: images, sounds, and texts. Deep learning models, such as convolutional neural networks (CNN) and recurrent neural networks (RNN), have proved to be effective in various cybersecurity tasks, from network intrusion detection to malware classification. It brings in brilliant performance for the processing of large amounts of data and drawing out intricate patterns that traditional ML models might miss (10).

Another important ML technique is reinforcement learning, in which models learn through interaction with their environment, proportioning reward and punishment formats to correctly optimize decision-making. Applied in cybersecurity, reinforcement learning enables dynamic threat detection and response effective over time since the exposed model learns from vast scenarios (9).

Basically, ML techniques help provide effective solutions to Cybersecurity measures by learning from a system's input data. These allow the detection of anomalies, threats classification, and the prediction of the attack event in turn, providing proactive defense against cyber threats.

VII. MACHINE LEARNING FOR ARP SPOOFING DETECTION

Several machine learning algorithms can be employed for detecting ARP Spoofing. These algorithms include decision trees, Support Vector machines (SVM), Random Forest, and Neural Networks. All these methods have their strengths and most importantly, they work differently in a variety of approaches to identify and classify possible attacks on ARP Spoofing.

1) Decision Trees: It's a classification model that classifies the data using a recursive split method according to the selected attributes. It is easily understood and runs very efficiently at runtime and for this reason, it is used in real-time detection systems. The classification branches from the root node to the leaf nodes, representing decision rules that guide the detection process. Decision Trees have traditionally been one of the principal techniques used in data classification.

2) Support Vector Machine: These are effective classifiers that draw a hyperplane in a space to be able to best separate the different classes of data. It is good at doing binary classification, so it detects normal traffic from ARP Spoofing attempts. However, sometimes it needs some thorough parameter tuning and, in some cases, data preprocessing (3).

3) Random Fores: It's an ensemble of Decision Trees used to make the classification earlier and prevent overfitting. Each tree gives a classification vote, and the majority vote will be the final classification. This methodology improves robustness and accuracy in determining ARP Spoofing attacks.

4) Neural Networks: It can capture strong, complex patterns present in network traffic. The multilayer neural networks, or deep learning models, are capable of pinpointing very subtle anomalies that present the ARP spoofing methodology by having learned from large amounts of labeled data. There is the development of a method within our research, using neural networks for the analysis of TCP, UDP, and ARP traffic and an alerting mechanism for notification of ARP attacks to the end user (6).

5) Long Short-Memory (LSTM): It's a type of artificial neural network, that is particularly suited for processing sequential data. This is based on deep learning. Within ARP Spoofing detection, they enable the effective analysis of temporary patterns of network traffic, thus providing a robust method for the identification of anomalies indicative of ARP attacks (8).

Feature selection forms one of the key developing parts of an efficient ARP Spoofing detection model. In this respect, important features of ARP Spoofing detection are packet patterns, anomalies in the MAC address, and traffic behavior. Features are chosen and extracted depending on the characteristics relevant to their application for the training of above machine learning models according to the conducted research using mentioned methodology. Packet Patterns: Any periodicity or any other anomaly in the pattern of packet transmission may indicate ARP Spoofing. MAC Address Anomalies: This includes inconsistencies in the MAC address, such as multiple IP addresses resolving to one MAC address, which can indicate spoofing. Traffic Behavior: Suspicious patterns of network traffic refer to unpredicted increases or decreases in network utilization that might show the existence of an ongoing ARP Spoofing attack.

VIII. CONCLUSION

This research conceptually explores the potential of machine learning algorithms to enhance ARP spoofing detection, a critical need in today's cybersecurity world.Traditional detection methods are useful but fall short in addressing the complexities and sophistication of current ARP spoofing techniques. The machine learning models evaluated in this work, among others, include Decision Trees, SVM, Random Forest, Neural Networks, and LSTM networks, which show very encouraging results in the identification of ARP Spoofing attempts. The different models detect the ARP spoofing attacks by using different features, including packet pattern, MAC address anomaly, or traffic behavior that unveils an anomaly indicative of a spoofing attack. These results indicate that machine learning can provide proactive and dynamic defense capabilities within cybersecurity frameworks against network threats. Future research should focus on optimizing these models for deployment in diverse network environments and exploring their applicability to other forms of cyber-attacks.

REFERENCES

[1] N. Tripathi and B. M. Mehtre, "Analysis of various arp poisoning mitigation techniques: A comparison," in *2014 international conference on control, instrumentation, communication and computational technologies (ICCICCT)*. IEEE, 2014, pp. 125–132.

[2] A. Al-Hababi and S. Tokgoz, "Man-in-the-middle attacks to detect and identify services in encrypted network flows using machine learning," 09 2020, pp. 1–5.

[3] M. Saed and A. Aljuhani, "Detection of man in the middle attack using machine learning," in *2022 2nd International Conference on Computing and Information Technology (ICCIT)*. IEEE, 2022, pp. 388–393.

[4] V. Rohatgi and S. Goyal, "A detailed survey for detection and mitigation techniques against arp spoofing," in *2020 fourth international conference on I-SMAC (IoT in social, mobile, analytics and cloud)(I-SMAC)*. IEEE, 2020, pp. 352–356.

[5] D. R. Rupal, D. Satasiya, H. Kumar, and A. Agrawal, "Detection and prevention of arp poisoning in dynamic ip configuration," in *2016 IEEE International Conference on Recent Trends in Electronics, Information & Communication Technology (RTEICT)*. IEEE, 2016, pp. 1240–1244.

[6] H. Abdulla, H. Al-Raweshidy, and W. S Awad, "Arp spoofing detection for iot networks using neural networks," in *Proceedings of the Industrial Revolution & Business Management: 11th Annual PwR Doctoral Symposium (PWRDS)*, 2020.

[7] J. J. Kponyo, J. O. Agyemang, and G. S. Klogo, "Detecting end-point (ep) man-in-the-middle (mitm) attack based on arp analysis: A machine learning approach," *International Journal of Communication Networks and Information Security*, vol. 12, no. 3, pp. 384–388, 2020.

[8] M. Usmani, M. Anwar, K. Farooq, G. Ahmed, and S. Siddiqui, "Predicting arp spoofing with machine learning," in *2022 international conference on emerging trends in smart technologies (ICETST)*. IEEE, 2022, pp. 1–6.

[9] I. H. Sarker, A. Kayes, S. Badsha, H. Alqahtani, P. Watters, and A. Ng, "Cybersecurity data science: an overview from machine learning perspective," *Journal of Big data*, vol. 7, pp. 1–29, 2020.

[10] M. Ahsan, K. E. Nygard, R. Gomes, M. M. Chowdhury, N. Rifat, and J. F. Connolly, "Cybersecurity threats and their mitigation approaches using machine learning—a review," *Journal of Cybersecurity and Privacy*, vol. 2, no. 3, pp. 527–555, 2022.

Reinforcement Learning Driven Policy Optimization for Adaptive Traffic Control Systems

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***Abstract*— Traffic congestion at key intersections in Colombo has been a persistent issue, exacerbated by rising vehicle numbers and the limitations of traditional traffic control methods. Fixed-time signal schedules and manual interventions often fail to adapt to the city's fluctuating traffic patterns, leading to long queues, delays, and frustration for commuters. This research proposes an adaptive traffic signal control framework for a major intersection in Colombo, addressing these challenges by leveraging real-time traffic data collected through a strategically positioned camera near the junction. The system continuously monitors and assesses traffic flow patterns, using a Long Short-Term Memory (LSTM) network to predict upcoming traffic volumes. A hybrid control algorithm then integrates rule-based congestion management with a Deep Deterministic Policy Gradient (DDPG) agent, optimizing signal timings dynamically to respond to real-time traffic demands. Designed with cost-efficiency, low computational needs, and compatibility with existing infrastructure in mind, this framework aims to improve vehicle throughput, reduce waiting times, and alleviate congestion offering a scalable approach for urban traffic management.**

Keywords - Intelligent Transportation Systems (ITS), Real-Time Traffic Prediction, Urban Traffic Optimization, Long Short-Term Memory (LSTM) Network

I. INTRODUCTION

Traffic congestion is an intensifying challenge in cities globally, with significant repercussions for daily life, economic efficiency, and environmental health. As urban populations expand and vehicle numbers rise, traffic bottlenecks occur with greater frequency and severity. Conventional traffic management approaches, which depend on static, fixed-time signals, frequently fall short in adapting to the complex and fluctuating traffic conditions that characterize contemporary urban areas.

Traffic congestion remains a major concern in Colombo, the capital of Sri Lanka, especially at critical intersections that serve as central nodes within the city's transport network. These intersections, where multiple traffic streams converge, are among the most congested areas, resulting in intricate traffic patterns and extended delays. Colombo's existing traffic management system, which relies on fixed-time signal controllers supplemented by manual adjustments, is insufficient for managing increasing traffic volumes and complex flows, particularly during peak periods. This inefficiency highlights the pressing need for an adaptive traffic control solution capable of dynamically adjusting signal timings in response to real-time traffic conditions.

Current traffic management approaches in Colombo lack the real-time adaptability necessary for effective control. While CCTV cameras monitor some intersections, they primarily serve for footage recording rather than active traffic regulation. Additionally, the expense of installing multiple cameras per intersection limits broad deployment, particularly in a developing country like Sri Lanka facing economic constraints. This study addresses these challenges by designing an adaptive traffic signal control system for a major Colombo intersection, presenting a cost-effective and scalable framework suitable for wider application across Sri Lanka.

The proposed solution combines real-time data collection, advanced neural network models, and reinforcement learning algorithms to dynamically adjust traffic signal timings. A CCTV camera positioned at the intersection monitors traffic flow continuously, supplying data to a Long Short-Term Memory (LSTM) network that forecasts traffic volumes by utilizing both historical and live data inputs. These forecasts guide a Deep Deterministic Policy Gradient (DDPG) and rule based control combined reinforcement learning model to optimize traffic light sequences, aiming to increase vehicle throughput, decrease waiting times, and reduce congestion. A notable advantage of this approach is its ability to be tested within a SUMO simulation environment prior to real-world deployment, helping to mitigate unexpected costs associated with prototype development.

This approach's innovation stems from its ability to adapt to real-time traffic conditions while maintaining economic feasibility for a developing nation like Sri Lanka. Engineered to require minimal infrastructure and low processing capacity, the system is both cost-effective and readily integrable within current traffic management frameworks. By overcoming the limitations of traditional traffic control methods and presenting a scalable, affordable solution, this research

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offers considerable potential to enhance traffic flow and alleviate congestion in Colombo's urban landscape.

This research seeks to develop a comprehensive framework for adaptive traffic signal control that can be applied to other intersections in Colombo and comparable urban environments experiencing congestion issues. Anticipated benefits include increased efficiency in traffic management, minimized environmental impact, and heightened commuter satisfaction, all of which contribute to the goal of sustainable urban development.

II. Related Work

The field of traffic signal control has evolved considerably over the years, spurred by the increasing need to manage urban congestion and enhance traffic flow efficiency. This section provides a comprehensive review of key traffic signal control approaches, including static systems, adaptive strategies, and the application of reinforcement learning (RL) methods.

A. Static Traffic Signal Control

Static traffic signal control systems are still widely used in many areas, including Colombo, Sri Lanka. In these systems, parameters like phase durations and cycle times are set in advance, often based on historical traffic patterns. Although they perform adequately under consistent traffic conditions, they lack responsiveness to fluctuating and unpredictable circumstances, such as severe weather or peak congestion. Consequently, these fixed-timing systems frequently experience inefficiencies, as they are unable to adjust in real-time to varying traffic demands.

B. Adaptive Traffic Signal Control

Adaptive traffic signal control has emerged as a compelling solution to overcome the constraints of static systems. Numerous adaptive techniques have been developed, offering enhanced flexibility and responsiveness to real-time traffic conditions.

Genetic Algorithms (GAs): Genetic algorithms (GAs) optimize traffic signal parameters by encoding phase durations and timings as chromosomes, with the objective of reducing queue lengths and travel times through a fitness function [3][4]. Despite their effectiveness, GAs can be computationally demanding and may exhibit slow convergence rates.

Fuzzy Logic: This approach employs linguistic variables and fuzzy inference rules to manage uncertainty, determining signal timings using imprecise data [5][6]. Although effective in handling ambiguity, fuzzy logic systems can become intricate and may struggle to adapt to highly variable traffic conditions.

Reinforcement Learning (RL): Q-learning, a widely used reinforcement learning technique, identifies optimal signal timings by evaluating vehicle queues and adjusting green durations accordingly [7]. While advantageous, Q-learning is constrained by its discrete action space, which limits its effectiveness in managing continuous traffic fluctuations.

Swarm Intelligence: Ant Colony Optimization (ACO) techniques draw inspiration from social insect behavior to address combinatorial challenges in traffic management [1]. Although adept at navigating complex search spaces, ACO can face challenges in real-time applications due to its intensive computational requirements.

C. Advancements in Reinforcement Learning for Adaptive Traffic Control

Recent advances in adaptive traffic control, especially through reinforcement learning (RL), have greatly enhanced the optimization of vehicle flow in complex urban settings. Conventional traffic signal control approaches, like Webster's Formula and SCATS, relied on static models and struggled with fluctuating traffic patterns. In contrast, RL offers a dynamic, data-driven solution, allowing systems to learn optimal strategies through real-time interactions with their environment. RL's foundational framework is based on the Markov Decision Process (MDP), where agents take actions based on observed states to maximize cumulative rewards. Q-learning, a widely adopted RL technique, aids in estimating long-term value, and the introduction of Deep Reinforcement Learning (DRL) has further strengthened its effectiveness. By leveraging DRL, traffic control systems can manage complex environments and process high-dimensional data, such as real-time sensor inputs, without the need for manual feature engineering.

Reinforcement learning (RL) methods have proven highly effective in enhancing adaptive traffic control by adjusting dynamically to real-time traffic conditions. For instance, [11] illustrated how Q-learning could surpass traditional techniques by learning directly from live traffic patterns at individual intersections, with promising scalability to broader networked systems. Likewise, [12] reviewed the application of multi-agent reinforcement learning (MARL), where intersections function as autonomous agents that collaborate to optimize traffic flow across urban networks. This decentralized approach is essential for efficiently managing complex, interconnected urban intersections.

The capacity of Deep Reinforcement Learning (DRL) to handle complex data, such as visual inputs from traffic cameras, enables adaptive systems to adjust signal timings based on current traffic patterns. Real-world applications like the Surtrac system in Pittsburgh have demonstrated significant reductions in wait times and emissions. Moreover, [11] highlighted

the successful implementation of RL at an isolated traffic signal in Toronto, where real-time adaptation led to improved traffic flow. Additionally, [12] underscored the critical role of advanced simulation environments in validating RL models prior to deployment, ensuring these models are scalable and adaptable to diverse traffic conditions.

D. DDPG Reinforcement Learning Approach

The Deep Deterministic Policy Gradient (DDPG) algorithm provides substantial benefits for real-time traffic signal control, as demonstrated in Wu's research. A primary advantage of DDPG is its ability to manage continuous action spaces, which is crucial for making precise adjustments to traffic signal timings (e.g., modifying the durations of green, yellow, and red lights). In contrast, conventional reinforcement learning (RL) algorithms, such as Q-learning and Deep Q-Networks (DQN), are restricted to discrete action spaces, which can limit their effectiveness in complex traffic environments.

The actor-critic architecture of DDPG enables it to function effectively within high-dimensional state and action spaces, allowing it to process complex, multi-dimensional inputs such as vehicle counts, waiting times, and road occupancy. This capability facilitates the formulation of advanced policies that can adjust to diverse traffic patterns, in contrast to simpler reinforcement learning algorithms that may face challenges in similar environments.

[4] Demonstrates that DDPG achieves quicker convergence and more consistent performance than DQN and Normalized Advantage Function (NAF) algorithms in simulation environments. The incorporation of experience replay in DDPG significantly boosts learning efficiency, enabling the agent to utilize past experiences to enhance policy robustness—an essential factor for effective traffic management. With its capability to handle continuous action spaces and multi-dimensional state variables, DDPG stands out as an optimal choice for real-time traffic signal control, showcasing its potential to alleviate congestion and improve traffic flow.

E. Camera Based Traffic Detection Systems

The growing intricacy of urban traffic necessitates efficient, real-time solutions for vehicle detection and classification. Camera-based approaches, especially those employing sophisticated deep learning models, have demonstrated strong reliability in traffic surveillance [10]. CCTV cameras play a pivotal role within Intelligent Transportation Systems (ITS), significantly enhancing incident detection, vehicle tracking, and overall traffic management effectiveness.

The YOLOv8 model is distinguished by its precision, achieving a 77% accuracy during training and 96% accuracy in testing on a varied vehicle dataset. Its robust framework adeptly manages complex scenarios, including occlusion and vehicle overlap. Integrating YOLOv8 with CCTV systems presents significant promise for real-time vehicle detection, as its fast image processing capabilities enable responsive adjustments to traffic conditions. Additionally, data augmentation methods enhance detection accuracy, especially for smaller objects. In this research, deploying a CCTV camera at a strategic distance to observe vehicle movement at intersections effectively harnesses YOLOv8's capabilities, providing a dependable solution for real-time vehicle detection and supporting accurate urban traffic oversight.

F. Traffic Prediction systems

Long Short-Term Memory (LSTM) networks have emerged as a powerful approach for predicting traffic flow, as evidenced by [9]. Their study shows that LSTMs outperform traditional models such as random walk and support vector regression by effectively capturing complex temporal dependencies in traffic data, thereby achieving higher forecasting accuracy. The distinct architecture of LSTMs, which includes memory cells and gating mechanisms, enables them to model intricate traffic patterns over extended periods.

Implementing LSTM networks can also result in considerable cost savings by minimizing the need for numerous cameras at intersections. Instead, a single camera, supplemented by date and time data, can estimate traffic volumes on adjacent roads. This method not only reduces installation and maintenance expenses but also streamlines data collection, providing an efficient solution for traffic management. The effective use of LSTM networks in traffic flow prediction highlights their reliability and cost-efficiency, empowering traffic authorities to optimize resource use and improve overall traffic flow management.

III. PROPOSED SYSTEM DESIGN

A. Proposed Framework

The proposed adaptive traffic signal control system aims to alleviate congestion at urban intersections through the application of advanced machine learning and reinforcement learning methods. This system comprises three core elements: a YOLO model for real-time, vision-based vehicle detection, a Long Short-Term Memory (LSTM) network for predicting traffic flow, and a Deep Deterministic Policy Gradient (DDPG) reinforcement learning algorithm to optimize traffic signal timing.

B. *Data Flow in the Proposed Framework*

In the proposed system, data flow begins with the capture of a live video feed from a CCTV camera positioned at the intersection to monitor traffic on one of the approaching roads. The YOLO model processes this video feed in real time, extracting critical traffic information. This processed data, combined with additional contextual information such as date and time, is then fed into the LSTM network for further analysis.

The LSTM network is responsible for forecasting traffic flow on the other three roads that meet at the intersection. By analyzing data processed by the YOLO model, the LSTM network produces accurate traffic predictions by drawing on both historical traffic patterns and current data. This predictive capability minimizes the need for multiple cameras and reduces processing requirements, allowing the system to estimate traffic conditions across all intersection approaches using information from just one camera.

After generating traffic predictions, the output data is fed into a DDPG-based reinforcement learning (RL) model. This RL model leverages the predictions to determine the most efficient sequence for traffic signals at the intersection. The key objectives are to enhance vehicle throughput, decrease wait times, and limit queue lengths by dynamically adjusting signal timings based on real-time traffic conditions. By integrating the YOLO model, LSTM network, and DDPG-based RL model into a single cohesive framework, this system offers an adaptive, cost-efficient approach to managing traffic, capable of adapting to the continuously shifting demands of urban environments.

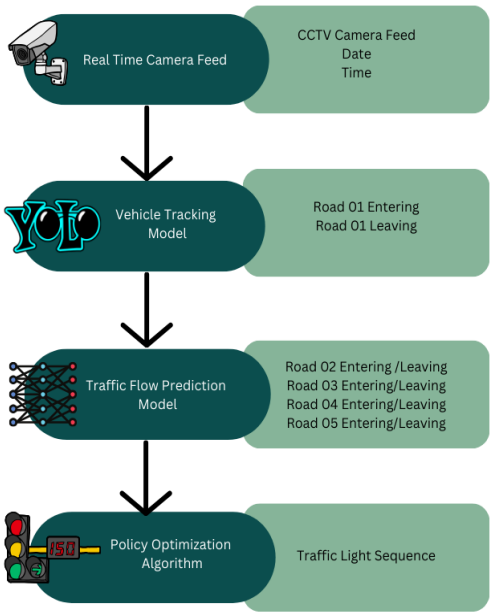

Fig. 1. Flow of Proposed Framework

IV. METHODOLOGY

A. *Traffic Perception Survey*

Before selecting the Borella intersection for this study, an in-depth traffic perception survey was conducted to confirm that the site accurately represented common traffic conditions and challenges. The survey, administered online to a random group of intersection users, gathered initial data on traffic trends, peak congestion hours, and frequent issues with traffic flow. Additionally, data provided by the Borella Police Station offered valuable insights into the volume and complexity of traffic at this location. These combined findings identified Borella as a high-demand area with complex traffic dynamics, making it a suitable focal point for this research.

B. *Data Collection*

Data collection for this study was conducted in two structured phases to ensure dataset accuracy and reliability. The initial phase utilized CCTV footage from the Colombo City Police's CCTV division. However, variability in footage quality and coverage led to the need for a second data collection phase to acquire a more dependable dataset.

In the second phase, a V380 Pro WiFi outdoor camera was strategically installed at a construction site near the Borella intersection to continuously capture footage for three weeks. Prior to installation, necessary permissions were obtained from the property owners as well as the Borella and Colombo North Police Stations to ensure compliance with local regulations. This study adopted a single-camera strategy, chosen for its cost-effectiveness and ease of implementation. The V380 Pro, equipped with a wide-angle dual-lens, offered comprehensive coverage of the intersection from a distance, reducing the need for multiple cameras. With a 128GB micro SD card, the camera provided sufficient storage for extended recordings. Its real-time monitoring capabilities allowed for remote access through a dedicated mobile application, facilitating regular status checks and effective management of the SD card, thereby ensuring smooth data collection throughout the duration.

The V380 Pro camera's night vision capability offered clear footage during night time, marking a notable enhancement compared to the police surveillance cameras utilized in the initial phase. The camera installation required only a power supply and a SIM card with adequate data capacity for connectivity, making it a cost-efficient and practical option for capturing traffic data at the intersection. The recorded videos were stored in AVI format and subsequently converted to MP4 for further analysis. VLC Media Player facilitated efficient transcoding, ensuring the video files were transformed into a more accessible format for processing and examination.

Fig. 2. Camera installed at the intersection

C. Vehicle Detection model

The gathered CCTV data will be used to train a vehicle detection and counting model utilizing YOLOv8l. This adaptive traffic signal control system incorporates the YOLO (You Only Look Once) framework for real-time vehicle detection and tracking, which is crucial for efficient traffic management at urban intersections. Leveraging the ultralytics/yolo framework, the YOLOv8l model is optimized for rapid processing, allowing for the real-time classification of identified objects such as cars, buses, and motorcycles.

To improve detection capabilities, the YOLO model is integrated with the Deep SORT (Simple Online and Realtime Tracking with a Deep Association Metric) algorithm. This combination enables the system to not only identify vehicles but also track them across multiple frames, assigning a unique identifier to each vehicle that remains until it leaves the scene.

Furthermore, the system includes functionalities for vehicle counting and speed estimation by establishing reference lines at the intersection. These lines serve to tally vehicles as they enter and exit different roads. Speed is estimated by analyzing vehicle movement across frames in relation to these reference lines. The system also gathers and utilizes contextual information, such as date, time, and estimated vehicle speed. To fine-tune the YOLO model for the Borella intersection, video data capturing both daytime and nighttime traffic—including peak and off-peak periods, as well as challenging conditions like inclement weather—will be extracted and annotated. A custom labeling system has been developed to distinguish vehicle appearances in day and night scenarios, enhancing the model's ability to detect and track vehicles under varying lighting conditions.

The annotated dataset will serve to train the YOLO model, improving its performance in detecting and tracking vehicles under various lighting and traffic conditions. A notable aspect of this YOLO model is its customization for the Borella intersection, which facilitates effective vehicle counting and tracking during both daytime and night time. This tailored approach enhances the model's robustness and accuracy across different lighting environments, which is essential for ensuring consistent performance throughout both day and night.

D. Traffic Demand Analysis

After gathering traffic data through camera footage, an extensive traffic demand analysis was conducted to examine patterns at the Borella intersection. The YOLO model was utilized to effectively detect and categorize vehicles, allowing for a thorough evaluation of traffic volumes, peak times, and daily fluctuations in flow. This analysis revealed periods of high and low traffic, offering valuable insights into congestion levels throughout the day.

E. Traffic Flow Prediction model

The traffic volume prediction module of the proposed system employs a Long Short-Term Memory (LSTM) network, a specific kind of recurrent neural network (RNN) designed for analyzing time-series data. This LSTM model forecasts traffic volumes at an intersection by utilizing real-time data from one road and leveraging patterns learned from historical traffic information. This method reduces the necessity for multiple cameras, thereby lowering monitoring expenses. Built using TensorFlow and Keras, the model's architecture is optimized through the RandomSearch algorithm from Keras Tuner to achieve the best hyperparameter configurations.

The input data, sourced from the outputs of the YOLO model (including date, time, and traffic volumes), undergoes processing through six traffic-related metrics and is standardized using a StandardScaler to improve training efficiency. These inputs are then reshaped to fit the LSTM's required format. Comprehensive hyperparameter tuning is conducted to minimize the mean absolute error (MAE) on a validation dataset. To mitigate overfitting and enhance performance, techniques such as early stopping and model checkpointing are implemented during training. Once the network is trained, it forecasts traffic volumes on other roads at the intersection using real-time inputs and learned historical patterns.

F. Policy Optimization Algorithm

The proposed traffic control system utilizes a hybrid algorithm that integrates a rule-based congestion management mechanism with the

adaptability of a Deep Deterministic Policy Gradient (DDPG) agent. This dual-approach framework is designed to provide both immediate response to traffic changes and long-term optimization, ensuring flexible and adaptive traffic light control. The hybrid model's foundation rests on two primary methodologies: rule-based traffic control for real-time adjustments and reinforcement learning for progressive, adaptive improvements.

1. Rule-Based Traffic Control Logic

The rule-based segment of the model operates by calculating congestion factors based on vehicle count, waiting time, and queue length at intersections. Using predefined weights and threshold rules, this approach determines the optimal duration for each traffic light phase in response to immediate conditions:

Congestion Calculation and Adjustment: This segment employs a weighted formula to calculate congestion levels, applying adjustments such as extending green phases or initiating early shifts based on current vehicle counts, waiting times, and queue lengths. This ensures rapid responsiveness to real-time traffic patterns.

Reward Assessment: After each phase shift, rewards are calculated to determine whether the action has successfully improved traffic flow. By evaluating changes in traffic parameters (e.g., vehicle count, waiting time), the rule-based method provides real-time reactivity without dependence on historical data. This ensures reliable performance under varying congestion levels, forming the system's immediate response layer.

This rule-based approach serves as the foundational control layer, effectively managing traffic flow in real time, independent of accumulated experiences or predictive models.

2. Adaptive Reinforcement Learning with DDPG

The DDPG component enhances the rule-based layer by learning optimal traffic light timings through reinforcement learning, prioritizing long-term traffic efficiency over immediate response. Key aspects of the DDPG component include:

Continuous Action Spaces: DDPG, a reinforcement learning algorithm suited to continuous action spaces, allows for fine-tuned adjustments to green light durations, enabling levels of precision beyond the capabilities of rule-based models.

Actor-Critic Framework: The DDPG agent consists of two neural networks: an actor network, which determines the timing of each traffic light phase, and a critic network, which assesses the expected cumulative reward of these actions. This setup enables the DDPG agent to iteratively improve traffic control policies by optimizing decisions based on historical interactions with the traffic environment.

Learning and Policy Optimization: By leveraging experience replay, the DDPG agent refines its policy over time. It optimizes decisions by focusing on long-term rewards, determined through a custom reward function accounting for factors such as traffic flow, waiting times, and queue lengths. This adaptive approach allows the DDPG agent to enhance congestion management through gradual learning, making it an ideal reinforcement learning component for long-term optimization.

DDPG was selected for its capacity to handle continuous action spaces, a crucial feature for managing variable green light timings. Compared to alternative reinforcement learning algorithms such as Q-learning, which is limited to discrete actions, or DQN, which does not support continuous actions natively, DDPG excels at refining actions with precision, making it particularly suitable for complex, adaptive traffic signal control. Furthermore, the actor-critic architecture of DDPG provides efficient policy optimization and faster convergence in large-scale environments. Benchmarks with other algorithms such as DQN and PPO revealed that DDPG offered superior adaptability and responsiveness in the context of traffic signal management, thus supporting its role in this hybrid control system.

3. Hybrid Decision-Making Model

The hybrid model—combining rule-based real-time adjustments with adaptive reinforcement learning—ensures a balanced approach to traffic signal control. The rule-based layer provides immediate adjustments based on real-time congestion data, while the DDPG agent refines traffic light patterns over time. This adaptive, dual-layered framework achieves robust responses to traffic fluctuations, delivering an optimal traffic flow solution capable of evolving with the complexity of urban intersections.The output of this system is an adaptive traffic light sequence that not only adjusts in real time but also learns to optimize green light durations over recurring patterns, resulting in efficient traffic management.

Initially, the RL agent is trained within a controlled, simulated environment that represents a range of traffic scenarios (e.g., low, average, and high traffic). The agent interacts with this simulated environment to adjust traffic light timings dynamically, learning optimal actions that minimize congestion and enhance flow. Through trial and error, the agent develops policies that can adaptively control traffic signals based on congestion patterns, queue lengths, and waiting times.

After establishing baseline performance in simulation, real-world data collected from the targeted intersection is fed into the simulated environment. This phase involves re-creating real-world traffic conditions within the simulation so the RL model can further refine its decision-making under authentic conditions. The agent's performance is rigorously evaluated within this simulated-real scenario, ensuring it achieves the

expected optimization levels that were demonstrated in simulation training.Once RL model reaches its performance benchmarks using real-world data within the simulated environment, the framework is deemed viable for real-world implementation.

G. Simulation Model

The Simulation of Urban Mobility (SUMO) platform was used to develop, train, and test this hybrid model in a simulated traffic environment. SUMO provides a controlled, realistic urban setting where the rule-based and DDPG components can be tested independently and in conjunction. By simulating varying levels of traffic density and intersection demands, SUMO allows the system to be iteratively refined to handle diverse real-world traffic scenarios. This simulation framework is essential for:

Baseline Comparisons: The model's performance was compared against traditional static traffic signal systems, focusing on metrics like vehicle throughput, average waiting time, and queue lengths.

Real-Time Adjustments: SUMO enables precise measurement of congestion factors like queue lengths, which are challenging to track in real-life settings. This ensures that both rule-based and DDPG models receive accurate, real-time data, allowing for high-fidelity testing of the hybrid system's adaptive and rule-based capabilities.

This SUMO-based simulation framework allows the hybrid model to be refined and rigorously tested, providing insights necessary for potential real-world deployment.

V. RESULTS

Initial progress has been made in several key areas of the project. The traffic perception survey results at Borella Junction, illustrated in Figure X, indicate substantial congestion during peak morning hours, with consistently high waiting times throughout the day and reduced delays during night time hours.

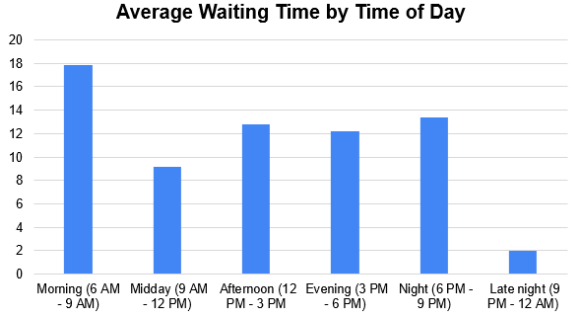

Fig. 3. Results of Traffic Perception Survey

The data collection phase was completed successfully, involving 24-hour monitoring over three consecutive weeks using a Wi-Fi CCTV camera installed at the Borella intersection. This process yielded a comprehensive dataset of 640GB, as shown in Figure Y.

Fig. 4. Frame obtained from CCTV footage

Figure 7 illustrates the traffic demand analysis, revealing the identified traffic patterns, peak hours, and variations in flow throughout the day for each road at the intersection.

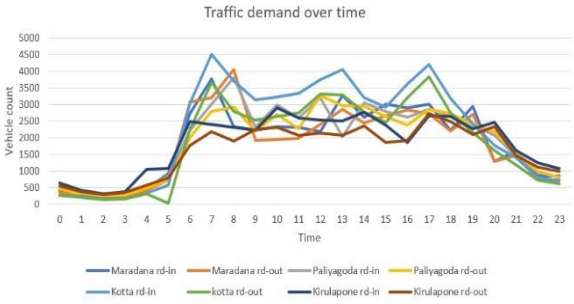

Fig. 5. Results of Traffic Demand Anslysis

The YOLO model was successfully created and evaluated, showcasing its capability to detect vehicles, count them, and log timestamps from recorded footage. Additional fine-tuning was performed using footage from the Borella intersection camera to adapt the model to the specific conditions of the location. Over 300–500 frames were annotated, and the model was retrained to manage diverse traffic volumes, weather variations like rain, and different lighting conditions, including day

and night, until the desired performance level was reached.

Fig. 6. Annotated frame from the obtained footage

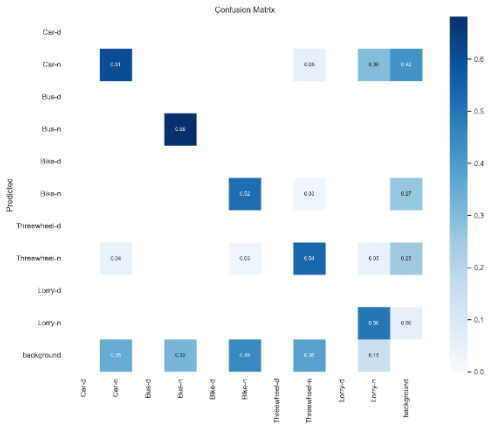

Fig. 7. Confusion Matrix of YOLO Model

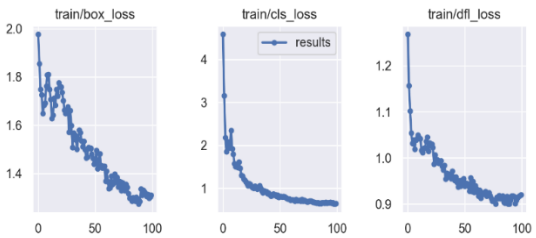

Fig. 8. Performance of YOLO Model

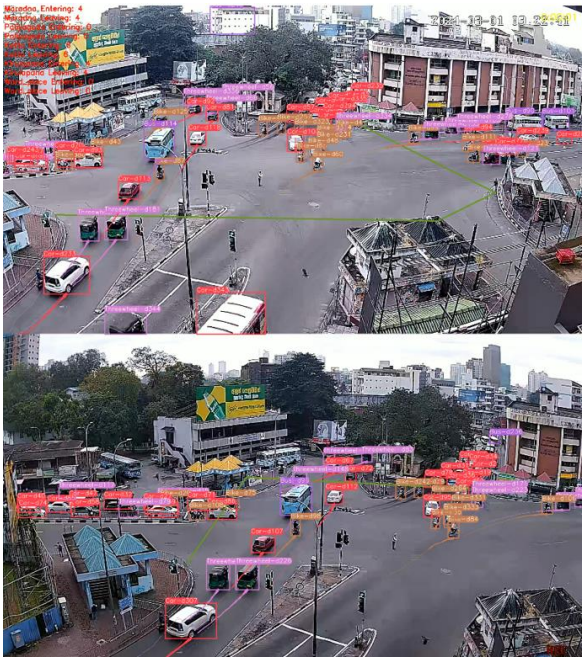

Fig. 9. Processed frame using YOLO Model

Two neural network architectures were initially developed for traffic flow prediction: a feed forward neural network and a long short-term memory (LSTM) network. Each model was trained independently, and their performance metrics were compared. The LSTM network was chosen for deployment due to its superior ability to capture temporal dependencies inherent in time-series data, such as traffic patterns. Comparative results demonstrated a significant advantage of the LSTM model in terms of accuracy and predictive reliability for traffic flow analysis.

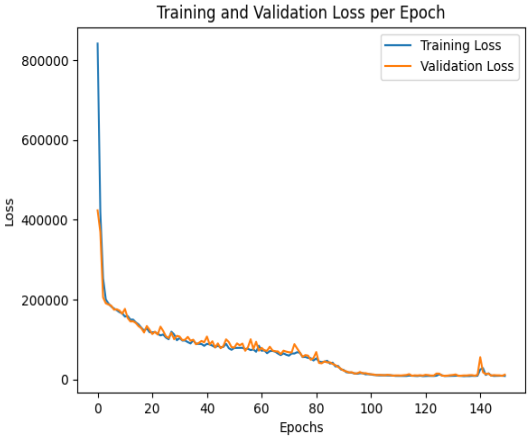

Fig. 10. Performance of Feed Forwad Neural Network

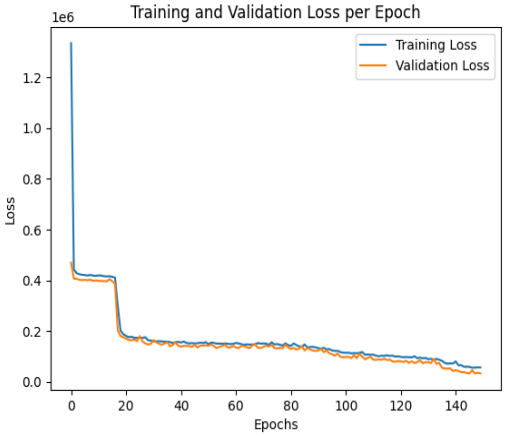

Fig. 11. Performance of LSTM Network

During the training phase, the LSTM model was tested with multiple scenarios to identify the optimal road input for predicting traffic patterns at the intersection. After evaluating various options, Maradana Road consistently yielded superior predictive performance, making it the preferred input for generating predictions across other roads. Key metrics used to assess model performance included convergence speed, final loss values, overfitting, and stability. Convergence speed measured how quickly losses decreased, while final loss values indicated accuracy. Overfitting was evaluated by the divergence between training and validation losses, and stability was assessed by the consistency of the loss curve post-initial drop.

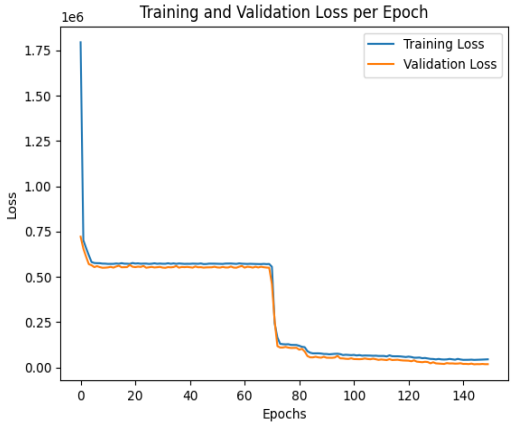

Fig. 12. Performance of LSTM model when predicting with Baseline-Paliyagoda as input

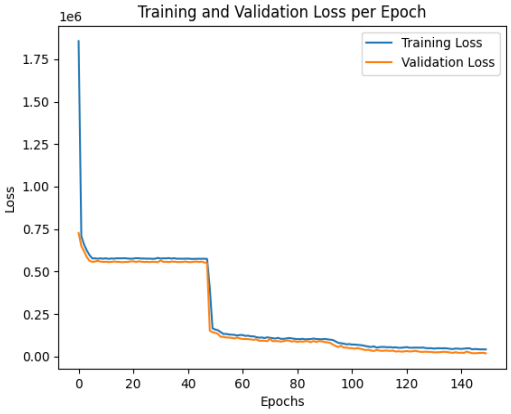

Fig. 13. Performance of LSTM model when predicting with Baseline – Nugegoda Road as input

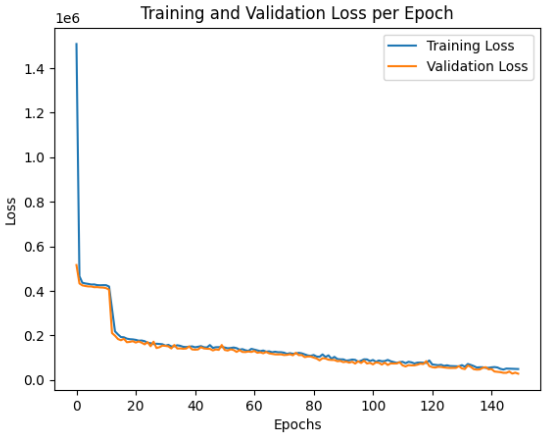

Fig. 14. Performance of LSTM model when predicting with Kota Road as input

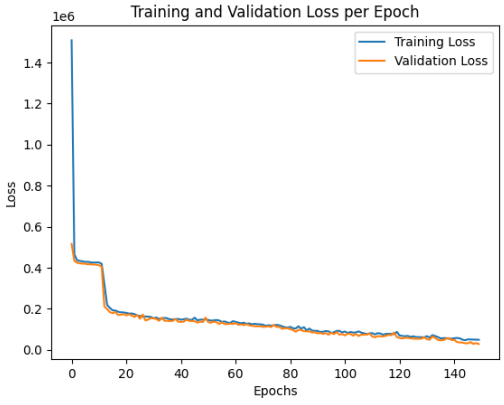

Fig. 15. Performance of LSTM model when predicting with Maradana Road as input

The LSTM model's performance on the test dataset for the "BN enter" variable highlights both strengths and limitations. It accurately captures overall traffic trends, with good alignment between predicted and actual values, demonstrating strong generalization. However, it underestimates peak values during rapid fluctuations, exhibiting a smoothing effect that reduces responsiveness to sharp changes. Additionally, a slight lag in predictions is observed around major peaks and troughs, limiting its ability to capture short-term variability. Consequently, while suitable for long-term trend forecasting, the model is less effective for precise, minute-to-minute predictions.

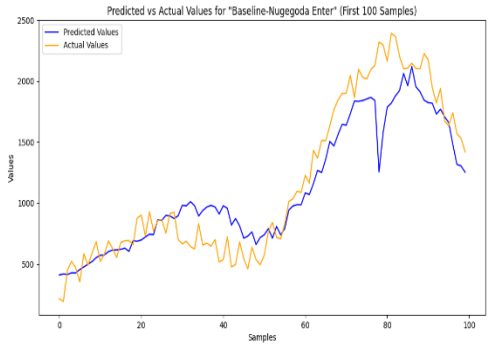

Fig. 16. Tested Accuracy of LSTM Network

The SUMO network simulating the RL environment has been successfully built using OpenStreetMap data. A Hybrid Decision-Making Model is in place, but it is still in the exploratory phase. Additional fine-tuning is required to refine the algorithm, enhancing its ability to effectively leverage actions and reach the intended results.

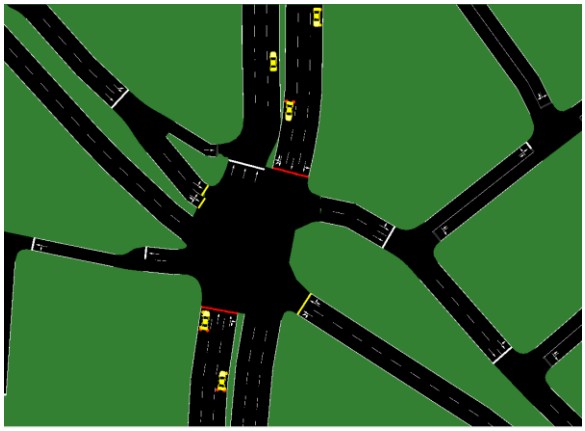

Fig. 17. SUMO Environment of the Intersection

VI. CONCLUSION

The proposed adaptive traffic management solution presents a significant advancement over existing systems, particularly in its computational efficiency and flexibility in data acquisition. The training phase of the model necessitates considerable computational resources, including high processing power, memory, and GPU capabilities, due to extensive data processing across all roads at the intersection. However, during deployment, the system's processing power requirements are markedly reduced, as it focuses solely on real-time data from a single road at any given time. This dynamic approach not only minimizes infrastructure costs but also facilitates the implementation of an efficient traffic management system.

While the use of a camera for data acquisition was driven by its availability and ease of installation, it is important to note that it is not a strict requirement. The system is adaptable and can accommodate various sensor types based on availability, thus enhancing its versatility. The Long Short-Term Memory (LSTM) network utilized for traffic prediction has demonstrated commendable performance using real-world camera data, showcasing its ability to work effectively with different sensor data types. Furthermore, the integration of the YOLO object detection model with the DeepSORT tracking algorithm has proven successful in accurately detecting and counting vehicles, even under challenging conditions such as day/night transitions, variable lighting, and adverse weather.

However, several limitations have been identified. Data collection was constrained to a three-week period due to permission restrictions; extending this timeframe to 3-4 months would yield a more comprehensive dataset, enabling the capture of complex traffic patterns and special events, such as public holidays, which could enhance model performance. Additionally, data acquisition was limited to the Borella junction; expanding the data collection efforts to include nearby intersections would improve the system's capability to manage traffic more effectively across a broader area. The choice to utilize a camera, while convenient, also introduced computational inefficiencies. Replacing the camera with sensors could mitigate these issues, leading to lower processing power demands.

Looking ahead, future work should include the implementation of an activation mechanism based on performance consistency, which could enhance system robustness. This mechanism would automatically revert to rule-based control when the DDPG agent consistently underperforms, establishing performance thresholds and continuously monitoring the agent's efficiency to ensure reliable decision-making. Further research should also explore the real-world deployment of the proposed framework, with a focus on improving its ability to handle complex scenarios and evaluating its scalability across multiple intersections for broader application.

ACKNOWLEDGMENT

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REFERENCES

[1] J. Withanawasam and A. Karunananda, "Multi-agent based road traffic control optimization," in *2017 IEEE 20th International Conference on Intelligent Transportation Systems (ITSC)*, 2017.

[2] M. Sutharsan, S. Rajakaruna, S. Y. Jayaweera, J. A. C. M. Jayaweera, and S. Thayaparan, "Vision-based adaptive traffic light controller for single intersection," in *2020 5th International Conference on Information Technology Research (ICITR)*, 2020.

[3] K. Shingate, K. Jagdale, Y. Dias, and Fr. c Rodrigues Institute of Technology, "Adaptive traffic control system using reinforcement learning," *Int. J. Eng. Res. Technol. (Ahmedabad)*, vol. V9, no. 02, 2020

[4] H. Wu, "Control method of traffic signal lights based on DDPG reinforcement learning," *J. Phys. Conf. Ser.*, vol. 1646, no. 1, p. 012077, 2020.

[5] T. Mahmood, M. E. M. Ali, A. Durdu, and Electrical and Electronic Engineering, Selçuk University, Konya, Turkey, "A two stage fuzzy logic adaptive traffic signal control for an isolated intersection based on real data using SUMO simulator," *International Journal of Trend in Scientific Research and Development*, vol. 3, no. 4, pp. 656–659, 2019.

[6] W. A. C. J. K. Chandrasekara, R. M. K. T. Rathnayaka, and L. L. G. Chathuranga, "A real-time density-based traffic signal control system," in *2020 5th International Conference on Information Technology Research (ICITR)*, 2020.

[7] Y.-J. Lee and O. Min, "Long short-term memory recurrent neural network for urban traffic prediction: A case study of Seoul," in *2018 21st International Conference on Intelligent Transportation Systems (ITSC)*, 2018.

[8] R. T. Wakkumbura, B. Hettige, and A. Edirisuriya, "Real-time traffic controlling system using Multi-Agent technology," *J. Eur. Syst. Autom.*, vol. 54, no. 4, pp. 633–640, 2021.

[9] Shao, H., & Soong, B.-H. *Traffic flow prediction with Long Short-Term Memory Networks (LSTMs)*. Interdisciplinary Graduate School, Nanyang Technological University.

[10] Hati Telaumbanua, A. P., Larosa, T. P., Pratama, P. D., Fauza, R. H., & Husein, A. M. (2024). *Vehicle Detection and Identification Using Computer Vision Technology with the Utilization of the YOLOv8 Deep Learning Method*. Universitas Prima Indonesia, Fakultas Sains dan Teknologi, Kota Medan.

[11] Abdulhai, B., Pringle, R., & Karakoulas, G. J. (2003). *Reinforcement Learning for True Adaptive Traffic Signal Control*. Journal of Transportation Engineering, 129(3), 278-285.

[12] Wei, H., Zheng, G., Gayah, V., & Li, Z. (2021). *Recent Advances in Reinforcement Learning for Traffic Signal Control: A Survey of Models and Evaluation.*

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Abstract— This research offers a thorough examination of the state of e-prescription systems today, emphasizing how revolutionary they are in improving patient safety, precision, and operational effectiveness in the medical field. Evaluating technology frameworks and policy issues is the main goal, with an emphasis on security, privacy, implementation hurdles, and new technological developments. By resolving problems with handwritten prescriptions, enabling smooth prescription transfer to pharmacies, and decreasing patient safety hazards, e-prescription systems are essential in eliminating drug mistakes. Key security and privacy issues are examined in this analysis, with a focus on the significance of data protection guidelines and encryption techniques now in use to secure private patient data. Furthermore, the potential of cutting-edge technologies like blockchain and artificial intelligence (AI) to enhance decision-making, guarantee data integrity, and reduce fraud risks is evaluated. The complexity of real-world applications is highlighted by case studies from a variety of healthcare settings, which show both successful implementations and typical problems including high initial costs and provider opposition. In order to increase cost-effectiveness, strengthen data security requirements, and promote wider stakeholder adoption, the review's conclusion emphasizes the necessity for more study. Although e-prescription systems show great potential for improving prescription administration and encouraging safer healthcare delivery, these persistent issues must be successfully resolved in order to fully realize these advantages.

***Keywords*— Electronic Health Record(EHR), Electronic Medical Record, , E-Prescription System.**

I. INTRODUCTION

The rapid growth of digital technology has greatly impacted many fields, including healthcare. One major advancement is the e-prescription system, which replaces traditional paper prescriptions with electronic ones. This review looks at various aspects of e-prescription systems, focusing on their security, privacy, benefits, challenges, and new technologies.

E-prescription systems make it easier for healthcare providers to send prescriptions directly to pharmacies electronically. This change improves the accuracy and efficiency of prescribing medications, reducing errors that can occur with handwritten prescriptions. However, adopting e-prescription systems comes with important considerations, particularly around security and privacy (Shaw et al., 2021; Norouzi Aval et al., 2021). Protecting sensitive patient information is crucial in healthcare, and ensuring that electronic prescriptions are secure involves using strong security measures and following regulatory standards. This review will explore the current state of security and privacy in e-prescription systems, including best practices and potential weaknesses.

Besides security and privacy, e-prescription systems offer many benefits, such as better patient safety, streamlined workflows, and improved medication management. These systems can reduce errors from unclear handwriting, automatically check for drug interactions, and ensure prescriptions are filled accurately and quickly. They also create a detailed record of prescriptions, which is useful for both clinical and legal reasons. However, moving to electronic systems can also bring challenges, like technical problems, resistance to change, and the need for thorough

training (Shaw, Tania, Mamgai, and Malhotra, 2021; Crisan and Mihaila, 2023; Alavi Amlashi, Kazemnejad Leyli, and Sheikhtaheri, 2022).Healthcare providers need to adjust to new software, which can disrupt their existing workflows. Integrating e-prescription systems with other healthcare information systems, like EHR, requires careful planning to ensure smooth data sharing and compatibility (Bin Saleem, Ali and AlSalloom, 2020; Selna et al., 2023; Salmanizadeh et al., 2022). Additionally, the cost of setting up and maintaining these systems can be a barrier, especially for smaller practices and those with limited funds.

Emerging technologies, such as Artificial intelligence(AI), blockchain, and telemedicine, are also shaping the future of e-prescription systems. AI can provide real-time insights and recommendations to help prescribers make better decisions. Blockchain technology offers a secure way to manage prescription data, potentially reducing fraud and improving data accuracy. These advancements can potentially address existing challenges and create new opportunities for enhancing the prescription process. Hence, the focus of this research paper is to address these critical questions:

1. What are the primary benefits and challenges of implementing e-prescription systems in healthcare?

2. What improvements are needed, and how are current e-prescription systems addressing security and privacy issues?

3. How will new technologies influence e-prescription systems in the future, and what are their drawbacks?

4. What crucial areas require further investigation to enable the effective integration of electronic prescription systems?

This review explores the various aspects of e-prescription systems, focusing on their security, privacy, benefits, challenges, and emerging technologies. By examining these questions, this study covers e-prescription systems, their current status, and their potential to improve healthcare delivery by looking at these issues. E-prescription systems, which emphasize the significance of continuous research in this developing sector, provide a viable route to safer, more effective healthcare management through the integration of digital technology.

II. LITERATURE REVIEW

The literature review examines the current state of research on developing and implementing EHRs and related healthcare information systems. Drawing on significant studies, it highlights the principles and practices that contribute to their effectiveness, security, and user satisfaction.

A. Adoption and Management Practices of EHR Systems

1. Management Practices in Healthcare Information Systems Adoption

   Crisan and Mihaila (2023) reviewed management practices in adopting healthcare information systems, emphasizing the importance of strategic planning, stakeholder engagement, and continuous training. The study highlights that successful EHR implementation requires an integrated approach involving organizational change management and technological readiness.

2. Enhancing Patient Safety through EHR in Small Island Developing States

   Selna et al. (2023) explored the challenges of using EHR systems to enhance patient safety in Small Island Developing States (SIDS). Their findings indicate that limited resources and infrastructure constraints pose significant hurdles, requiring tailored strategies to adapt EHR systems to these regions' unique needs.

B. Security and Privacy in EHR Systems

1. Securing EHR Management with Internet of Things(IOT)

   Bin Saleem et al. (2020) proposed a framework for securing EHR management in the era of the IOT. Their study emphasizes the need for robust encryption protocols, access control mechanisms, and continuous monitoring to protect sensitive health data from cyber threats.

2. Privacy and Confidentiality in Electronic Prescribing Systems

   Norouzi Aval et al. (2021) conducted a review study focusing on security, privacy, and confidentiality in electronic prescribing systems. They identified common vulnerabilities and proposed comprehensive security measures, such as blockchain technology and multi-factor authentication, to safeguard patient information.

C. User Experience and System Performance

1. EHR User Experience and Hospital Safety Performance

   Classen et al. (2023) examined the relationship between inpatient EHR user experience and hospital safety performance. Their study found that user-friendly EHR interfaces and efficient workflows significantly improve patient outcomes and reduce medical errors.

2. Physician and Pharmacist Perspectives on Ambulatory E-Prescription Systems

Alavi Amlashi et al. (2022) explored the viewpoints of physicians and pharmacists regarding ambulatory electronic prescription systems. Their findings highlight the importance of user satisfaction, ease of use, and the integration of decision support tools to enhance the adoption of these systems.

D. Integration of Advanced Technologies

1. Automatic Medical Report Generation with Transformers

   Adornetto et al. (2023) developed an automatic medical report generation method using latent space conditioning and transformers. This approach leverages advanced AI technologies to streamline documentation processes, reducing healthcare providers' administrative burden.

2. AI Integration for Precision Medicine

   Tong et al. (2024) discussed integrating multi-omics data with EHR for precision medicine using advanced artificial intelligence. Their research underscores the potential of AI to enhance personalized treatment plans and improve patient outcomes through more accurate predictions and tailored interventions.

E. Challenges and Solutions in EHR Implementation

1. Barriers to Implementing E-Prescription Software

   Maatuk et al. (2022) identified barriers to implementing electronic prescription software in public hospitals, including resistance to change, lack of technical infrastructure, and insufficient training. They proposed solutions such as phased implementation, continuous education, and stakeholder involvement to overcome these challenges.

2. Addressing Non-Medical Reports in EHR Systems

   Peeya et al. (2023) tackled the issue of non-medical reports in EHR systems, developing a framework for detecting and removing irrelevant documents. This approach enhances the efficiency and accuracy of EHR systems, ensuring healthcare providers access relevant and up-to-date patient information.

F. Future Trends and Best Practices

1. Secondary Uses of Electronic Prescribing and Pharmacy Data

   Chaudhry et al. (2024) conducted a national survey on the secondary uses of electronic prescribing and pharmacy data in UK hospital care. Their study highlights the potential for using EHR data to improve clinical decision-making, support research, and optimize healthcare delivery.

2. Real-Time Health Monitoring and Wearable Devices

   Gao et al. (2020) demonstrated the benefits of integrating real-time health monitoring data from wearable devices into predictive models. This approach allows for continuous data collection and analysis, enabling more dynamic and responsive healthcare interventions.

This literature review examines various aspects of EHR systems to provide a comprehensive overview of the current state of research and identify key factors contributing to the successful implementation and utilization of EHR systems in healthcare.

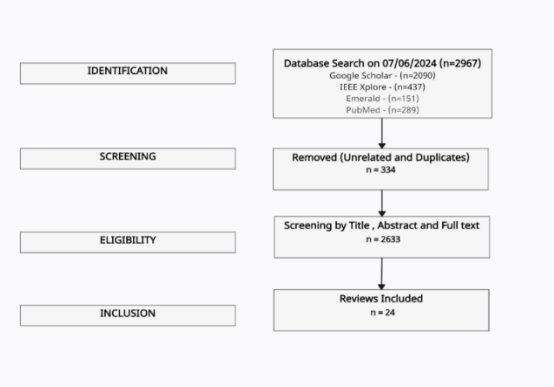
III. METHODOLOGY

This review study used a methodical approach with specific criteria for including and excluding studies. We focused on keywords like "Electronic Health Record," "Electronic Medical Record," "EHR," and "E-Prescription System" and related terms found in the articles' titles, keywords, and abstracts. The search was conducted on June 7, 2024, using trusted scientific databases such as Google Scholar, IEEE Xplore, Emerald, and PubMed.

The authors initially found 2967 articles. Out of these, 334 were not suitable for our study, so we excluded them. This left us with 2633 articles for a screening. Then, we chose 24 articles. Four researchers then independently examined these articles, each reviewing six articles. Any differences in the data or interpretations were discussed among the researchers to reach an agreement.

A survey was done with the literature research to get opinions from important parties, such as thirty pharmacies, fifty physicians, and one hundred patients. From June 10 to July 10, 2023, an online survey and in-person interviews were used to gather information on their experiences, difficulties, and opinions about e-prescription systems. Both quantitative and qualitative approaches to analysis were used to find trends, patterns, and themes in the survey data. To detect recurring themes, patterns, and gaps in the research and survey results, pertinent information from the chosen articles and survey replies was taken out and examined.

Figure 1. Study Selection Chart



Source: Author

IV.RESULTS AND DISCUSSION

As EHR systems continue to develop, it is important to focus on key areas like security, privacy, benefits, challenges, and new technologies. This discussion examines these important aspects of EHR systems, exploring how they can improve patient care and make healthcare operations more efficient. We'll also consider the challenges of keeping data secure and private and how emerging technologies might shape the future of EHR systems.

Table 1. Emerging Technologies and concerns related to particular areas

Source: Author

Paper	Main Areas	Technologies	Remarks
[1]	Adoption of healthcare information systems Management practices in healthcare	AI, Machine Learning (ML), Robotic Process Automation (RPA)	Initial Cost, Technical Complexity, Scalability Issues Operational Efficiency, Employee Roles, Customer Satisfaction Efficiency Improvements, Cost Reduction, Enhanced Accuracy
[2]	Securing EHR management IOT in healthcare	Big Data Analytics, Cloud Computing, IOT	Data Quality Issues, Complex Implementation, High Maintenance Costs Business Agility, Innovation, Customer Insights.
[3]	Challenges in using EHR Enhancing patient safety in Small Island Developing States (SIDS)	Blockchain, 5G Networks, Edge Computing	Dependency on Technology, Security Risks, Downtime Business Agility, Innovation, Customer Insights Enhanced Collaboration, Resource Optimization, Real-time Monitoring
[4]	Requirements for a medical records electronic deficiency management system Mixed-method study approach	Cloud computing, Big Data, AI	Unauthorized Access, Lost Keys, Symmetric Key Sharing, One Time Password(OTP) Insufficiency
[5]	Circular entrepreneurial ecosystems The Quintuple Helix Model approach	IOT, Blockchain, 5G Networks, Edge Computing	technology dependency, Security risks, Downtime Competitiveness, Transparency, Sustainability
[6]	Health information management systems, Clinical documentation quality, EDMS in hybrid environments, Feedback and training systems	EMR and EHR, DQA guidelines, Audit and feedback systems, Electronic checklists, Email and SMS reminders	Unstudied performance and Return Over Investment(ROI), Slow workflow changes, Gradual transition in developing countries Reduces errors and delays, improves documenter performance, Enhances medical records quality, and Affects financial and legal aspects.
[7]	Security of EHR	Encryption Techniques, Access Control Mechanisms, Authentication Protocols	Complexity, Cost, User Training, Integration Challenges Improved Patient Care, Efficient Data Sharing Enhanced Security, Privacy Protection,

			Data Integrity, Authentication
[8]	EHRs and their transition from paper-based systems to digital formats in healthcare	Cloud Computing, Blockchain, IOT	Centralized Structures, Performance Issues, Ownership Concerns, Fragmented Data Access Transformation of Healthcare, Global Information Exchange, Improved Healthcare Efficiency Improved Accessibility, Enhanced Security, Efficient Data Exchange, Reduced Redundancy
[9]	Automatic Medical Report Generation	Variational Autoencoder (VAE), Generative Pre-trained Transformer (GPT), Attention Mechanism	Interpretability Challenges, Ethical Considerations Healthcare Workflow Improvement, Diagnostic Accuracy Enhancement, Efficient Reporting Processes High-Quality Reports, Semantic Similarity Measurement, Enhanced Attention Mechanism, Model Interpretability
[10]	Quality Improvement in Healthcare	EHRs, Clinical Decision Support Systems (CDSS), Usability Testing Tools	Sample Representativeness, Voluntary Participation Bias, Need for Further Research Patient Safety, User Satisfaction, Quality of Care, Quality of Care, Organizational Efficiency Improved Patient Safety, Enhanced User Experience, Quality Improvement, Cost Reduction
[11]	Document Classification in EHR System	Optical Character Recognition (OCR), Machine Learning Algorithms, Data Analysis Tools Sentence Embedding and Vectorization Techniques	Dependency on Data Quality, Algorithm Performance, Generalizability Improved Patient Care, Advancement in Healthcare Research, Streamlined Data Management Improved Accuracy, Efficient Document Sorting, Enhanced Healthcare Data Management
[12]	Secondary Uses of Electronic Prescribing and Pharmacy Data in UK Hospital Care	Electronic Hospital Pharmacy (EHP) Systems, Electronic Prescribing (EP) Systems, Data Analysis Tools	Limited Response Rate, Exploratory Analysis, Temporal Data Collection Enhanced Patient Care, Policy Changes, Research Opportunities Improved Medication Safety, Quality Improvement, Cost-Effectiveness
[13]	Advantages and Challenges of EHR	EHRs utilize passwords, Bio-metrics, network firewall security	Quality healthcare services. Track Patient utilization and healthcare costs. Health Record Portability. Lower costs of healthcare.
[14]	EHR Development	MERN Stack	Seamless user interface (React). Dealing with unstructured data and repositories for a wide range of records (MongoDB). Manage authentication and income requests (Express). Fast and concurrent data processing (Node.js).
[15]	Exploring patient's	Data preparation and	72.15% of doctors were satisfied.

	experiences and Doctors' Satisfaction on EHR	analyses were conducted using Python 3.7.	Most patients refuse to use online medical systems. (Including different reasons).
[16]	Integrating Multi-Omics Data with EHR	High-throughput Sequencing, Wearable devices, Artificial Intelligence, Bioinformatics tools, Casual Inference Methods	Enhanced predictive accuracy. Comprehensive data utilization. Requires advanced technical skills in bioinformatics.
[17]	User acceptance and attitude, Implementation challenges, System performance.	Data encryption, Secure Data transmission protocols, Database Management System.	Improved accuracy. Enhanced Efficiency. Complexity. Regulatory and Legal issues.
[18]	Security and Privacy	Strong Infrastructures, Private Networks, Encrypted Communication, Cryptography, Smart Cards, Blockchain, Proxy signature Schemes	Protocols ensure security and confidentiality. Lack of international requirements.
[19]	Deep Learning in Text Redaction	AnonCAT, RoBERTa-Large, MedCAT, MedCATtrainer, Hyperparameter Tuning	High performance. Fine-Tuning. Ongoing Improvement. Generalizability challenges.
[20]	Handwritten Medical Prescription Recognition	3 Layered Neural Networks, Segmentation Technique, Python	Error Reduction. Environment-Friendly. Complexity. Data availability.
[21]	E-Prescription using Blockchain.	Blockchain, Ethereum Network, Smart Contracts, Web3.js, Ganache and Truffle	Decentralization. Transparency. Cost Reduction. Technical Complexity.
[22]	Barriers to implementation, Opportunities and benefits	Digital Signature, Communication Systems.	Error reduction. Efficiency. Cost savings. Technical barriers. Resistance to change.
[23]	Impact of EHR on the quality of nurse-patient interactions.	Mobile Trolleys	Improved Communication, Reduce documentation errors, Negative perception by nurses.

Integrating advanced technologies like AI, ML, and Robotic Process Automation (RPA) into healthcare systems has greatly improved efficiency and accuracy [1]. These technologies help cut costs, boost accuracy, and increase patient satisfaction. However, they come with high initial costs, technical difficulties, and scalability issues. Similarly, Big Data Analytics, Cloud Computing, and the IOT have transformed data management and analysis in healthcare [2]. These tools enable real-time data processing and foster innovation but also present challenges like data quality issues and complex implementation.

Emerging technologies like Blockchain, 5G Networks, and Edge Computing further enhance healthcare by improving patient safety and enabling real-time monitoring [3]. They offer benefits such as better collaboration and resource optimization but also introduce issues like dependency on technology and potential security risks. Cloud Computing, Big Data, and AI are crucial for managing electronic deficiency systems, offering benefits like improved data management but facing limitations such as unauthorized access and lost keys [4]. Technologies like OCR and Machine Learning Algorithms are important for document classification in EHR systems, improving accuracy and efficiency, though they depend heavily on data quality and algorithm performance [11].

While AI, ML, and RPA have significantly improved healthcare efficiency and cost reduction [1], they also face high initial costs and technical complexities. Big Data Analytics, Cloud Computing, and IoT enhance patient care with better documentation and real-time monitoring but are challenged by data quality and implementation issues [2][3]. Security remains a major concern, with risks such as unauthorized access and data breaches [4][7][18]. Moreover, EHR systems can sometimes negatively impact nurse-patient interactions by distracting from face-to-face communication [23]. Technologies like Blockchain and 5G Networks can also create reliance on complex systems that may affect patient care during technical failures [3][5].

While advanced technologies offer significant benefits for improving efficiency and patient care, they also bring high costs, technical issues, and security risks. Addressing these challenges through effective strategies and security measures is key to optimizing the benefits and enhancing healthcare delivery.

V. CONCLUSION

E-prescription technologies, which increase patient safety, accuracy, and efficiency, have transformed prescription administration in the healthcare industry. By eliminating the risks associated with handwritten prescriptions, these solutions streamline processes and provide more reliable drug administration. However, there are disadvantages to moving to electronic systems, including concerns about data security, privacy, technological limitations, and the need for integration with the present healthcare system and extensive training.

Emerging technologies like telemedicine, blockchain, and artificial intelligence provide promising solutions to these issues by improving access to prescription services, enhancing data privacy, and providing real-time information. Nevertheless, these advancements also provide new difficulties that must be effectively managed, such as adherence to regulations and other risks associated with developing technology. Healthcare providers may optimize the advantages of e-prescription systems and promote a safer, more effective, and future-ready approach to drug management by giving top priority to strong security measures, strategic planning, and continuous review.

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REFERENCES

[1] Crisan, E. L., and A. Mihaila, "Health-care information systems adoption – a review of management practices," Vilakshan – XIMB Journal of Management, vol. 20, no. 1, pp. 130-139, 2023, doi: 10.1108/XJM-04-2021-0121.

[2] W. Y. Bin Saleem, H. Ali, and N. AlSalloom, "A Framework for Securing EHR Management in the Era of Internet of Things," in 2020 IEEE International Conference on Future Internet of Things and Cloud (FiCloud), 2020, pp. 1-8, doi: 10.1109/FiCloudW.2020.0001.

[3] A. Selna, Z. Othman, J. Tham, and A. K. Yoosuf, "Challenges to using electronic health records to enhance patient safety, in a Small Island Developing State (SIDS) context," Management and Science University, Shah Alam, Malaysia; ADK Hospital, Malé, Maldives, 2023, doi: 10.1108/MD-08-2023-1361.

[4] F. Salmanizadeh, A. Ameri, L. Ahmadian, M. Mirmohammadi, and R. Khajouei, "Determining the requirements of a medical records electronic deficiency management system: a mixed-method study," Kerman University of Medical Sciences, Kerman, Iran, 2023, doi: 10.1108/RMJ-02-2022-0004.

[5] J. D. Borrero and S. Yousafzai, "Circular entrepreneurial ecosystems: a Quintuple Helix Model approach," University of Huelva, Spain; Nazarbayev University, Kazakhstan; Cardiff University, UK, 2023, doi: 10.1108/MD-08-2023-1361.

[6] F. Salmanizadeh, A. Ameri, L. Ahmadian, M. Mirmohammadi, and R. Khajouei, "Determining the requirements of a medical records electronic deficiency management system: a mixed-method study," Records Management Journal, vol. 32, no. 3, pp. 288-320, 2022, doi: 10.1108/RMJ-02-2022-0004.

[7] C. Adornetto, A. Guzzo, and A. Vasile, "Automatic Medical Report Generation via Latent Space Conditioning and Transformers," in 2023 IEEE Intl Conf on Dependable, Autonomic and Secure Computing, Intl Conf on Pervasive Intelligence and Computing, Intl Conf on Cloud and Big Data Computing, Intl Conf on Cyber Science and Technology Congress (DASC/PiCom/CBDCom/CyberSciTech), Abu Dhabi, United Arab Emirates, 2023, pp. 0428–0435, doi: 10.1109/DASC/PiCom/CBDCom/Cy59711.2023.10361320.

[8] N. T. Chaudhry, J. Benn, and B. D. Franklin, "Secondary uses of electronic prescribing and pharmacy data in UK hospital care: a national survey," BMJ Open Quality, vol. 13, no. 2, p. e002754, 2024, doi: 10.1136/bmjoq-2024-002754.

[9] D. C. Classen et al., "Inpatient EHR User Experience and Hospital EHR Safety Performance," JAMA Network Open, vol. 6, no. 9, p. e2333152, 2023, doi: 10.1001/jamanetworkopen.2023.33152.

[10] L. Negi and S. Bhatt, "A Review on security schemes for Electronic Health Records," in 2022 Fifth International Conference on Computational Intelligence and Communication Technologies (CCICT), Sonepat, India, 2022, pp. 37–41, doi: 10.1109/CCiCT56684.2022.00019.

[11] N. B. R. Peeya et al., "Detection and Removal of Non-Medical Reports from User Provided Paper-Based Documents for Generating an Efficient EHR System," in 2023 3rd International Conference on Smart Generation Computing, Communication and Networking (SMART GENCON), Bangalore, India, 2023, pp. 1–6, doi: 10.1109/SMARTGENCON60755.2023.10442851.

[12] B. V. Rani and P. Singh, "A Survey On Electronic Health Records (EHRS): Challenges And Solutions," in 2022 6th International Conference on Computing Methodologies and Communication (ICCMC), Erode, India, 2022, pp. 655–658, doi: 10.1109/ICCMC53470.2022.9754040.

[13] S. R. Alavi Amlashi, E. Kazemnejad Leyli, and A. Sheikhtaheri, "Physicians' and Pharmacists' viewpoint on ambulatory electronic prescription system," Journal of Health Administration, vol. 25, no. 3, 2022, doi: 10.22034/25.3.108.

[14] M. H. Da Fonseca et al., "E-Health Practices and Technologies: A Systematic Review from 2014 to 2019," Healthcare, vol. 9, no. 9, p. 1192, 2021, doi: 10.3390/healthcare9091192.

[15] S. Elkefi and O. Asan, "Exploring doctors' satisfaction with electronic health records and their features: A nationwide survey study," in 2022 IEEE International Symposium on Systems Engineering (ISSE), Vienna, Austria, 2022, pp. 1–5, doi: 10.1109/ISSE54508.2022.10005506.

[16] T. Shukla, K. Suri, and P. Sudhakaran, "Efficient Prescription Data Entry by EMR Software," in 2023 2nd International Conference on Automation, Computing and Renewable Systems (ICACRS), Pudukkottai, India, 2023, pp. 1314–1322, doi: 10.1109/ICACRS58579.2023.10404835.

[17] L. Tong et al., "Integrating Multi-Omics Data With EHR for Precision Medicine Using Advanced Artificial Intelligence," IEEE Reviews in Biomedical Engineering, vol. 17, pp. 80–97, 2024, doi: 10.1109/RBME.2023.3324264.

[18] S. F. M. B. R. Norouzi Aval, M. Sarbaz, and K. Kimiafar, "Security, privacy, and confidentiality in electronic prescribing systems: A review study," Frontiers in Health Informatics, vol. 10, p. 115, 2021, Available: www.ijmi.ir.

[19] Z. Kraljevic et al., "Validating Transformers for Redaction of Text from Electronic Health Records in Real-World Healthcare," in 2023 IEEE 11th International Conference on Healthcare Informatics (ICHI), 2023, pp. 1–10, doi: 10.1109/ICHI57859.2023.00098.

[20] U. Shaw, T. Tania, R. Mamgai, and I. Malhotra, "Medical Handwritten Prescription Recognition and Information Retrieval using Neural Network," in 6th IEEE International Conference on Signal Processing, Computing and Control (ISPCC 2k21), Solan, India, Oct. 07-09, 2021, pp. 1-6, doi: 10.1109/ISPCC53510.2021.9609390.

[21] S.-V. Ionescu, "E-prescription using blockchain technology," in 2022 IEEE International Conference on Blockchain, Smart Healthcare and Emerging Technologies (SmartBlock4Health), 2022, pp. 1-6, doi: 10.1109/SMARTBLOCK4HEALTH56071.2022.10034520.

[22] A. M. Maatuk, I. Denna, A. M. Elghriani, and A. A. Werfalli, "Barriers and Opportunities to Implementing Electronic Prescription Software in Public Libyan Hospitals," in 2022 International Conference on Engineering & MIS (ICEMIS), 2022, pp. 1-6, doi: 10.1109/ICEMIS56295.2022.9914258.

[23] C. Forde-Johnston, D. Butcher, and H. Aveyard, "An integrative review exploring the impact of Electronic Health Records (EHR) on the quality of nurse-patient interactions and communication," Journal of Advanced Nursing, vol. 78, no. 4, pp. 923–934, Oct. 2022, doi: 10.1111/jan.15484.

Assessment of Postharvest Loss of Banana Supply Chain in Sri Lanka

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***Abstract*- Banana is a popular crop grown worldwide due to its rising consumer demand. In Sri Lanka, bananas rank among the most extensively cultivated fruits, primarily because of the substantial demand within the local population. The current experiment was carried out to measure the postharvest loss of bananas when they move through the supply chain of fruits in Sri Lanka. The findings of this study revealed that the cumulative postharvest loss, spanning from the farm to the retailer market, stood at 19.2%. Notably, a comparatively higher loss occurred during the transportation phase from collection centers to the wholesale market, with a staggering rate of 50.8%. These losses can be attributed to several key factors, including suboptimal loading and unloading practices, inadequate proper transportation methods, and the absence of protective packaging materials during transportation and storage. To mitigate these losses and enhance the overall efficiency of the banana supply chain, it is imperative to identify and implement feasible practical measures. Additionally, knowledge dissemination to all stakeholders should be a focal point, with government support playing a crucial role in facilitating these improvements. The study was conducted in Kurunegala district, North Western Province in Alawwa,28.2 km from Kurunegala for data collection. Data analysis was performed using Microsoft Excel and SPSS. Excel was used for initial data organization, while SPSS was employed for statistical analyses. The primary data were augmented with secondary data collected from various articles and publications.**

Keywords— Fruit supply chain, Postharvest losses, Mitigation measures

1. INTRODUCTION

Banana, scientifically classified as *Musa* spp. and a member of the Musaceae family, holds a prominent position as the fifth-largest agricultural food crop on a global scale. It thrives in over 130 nations, primarily within tropical and subtropical regions, with Sri Lanka emerging as a noteworthy cultivator. Bananas rank among the top 20 key global food commodities and represent a robust tropical perennial crop [1].

Usually, considerable land extent is cultivated with bananas showing the significant role played by the crop within the country. It has become a dietary cornerstone in the country, serving as a crucial source of nutrients. Notably, in recent years, this fruit, highly favored by the Sri Lankan population, has demonstrated a substantial positive impact on the health and nutritional status of the population, particularly among individuals in lower socioeconomic strata [2]. There are many banana varieties grown within the country and almost all of them have a continuous demand from the consumers. To provide a sufficient supply for the rising demand bananas are commercially produced within the farms on large scales.

The economic impact of fruit losses is significant, leading to reduced income for farmers, increased food prices for consumers, and a waste of valuable resources used in cultivation, transportation, and distribution. Around 210,000 mt of fruits are lost annually during postharvest operations, up to 30% to 40% of the harvest. Normally, postharvest losses are due to poor handling, pests and pathogens, improper storage, moisture and drying, temperature fluctuations, lack of infrastructure, and inadequate packaging. Since bananas are a climacteric perishable fruit crop, their postharvest losses are often considerable and typically occur during transportation and handling in the supply chain [3]. The current study was conducted to investigate the possible postharvest losses that occur in the supply chain of bananas within Sri Lanka, the reasons behind the losses, and possible measures that can be implemented to minimize the losses as a developing country.

2. METHODOLOGY

The study was conducted in Alawwa, which belongs to the Kurunegala district, North Western province of Sri Lanka. The study zone encompassed two farm gates, at Kandegedara and Malhewa. These farms were situated at a distance of 2.5 km and 3.5 km, respectively from the collection center known as Maharacchimulla. Storage time in collection centers was approximately 48 hours (2 days). Furthermore, this research extended to the downstream distribution.

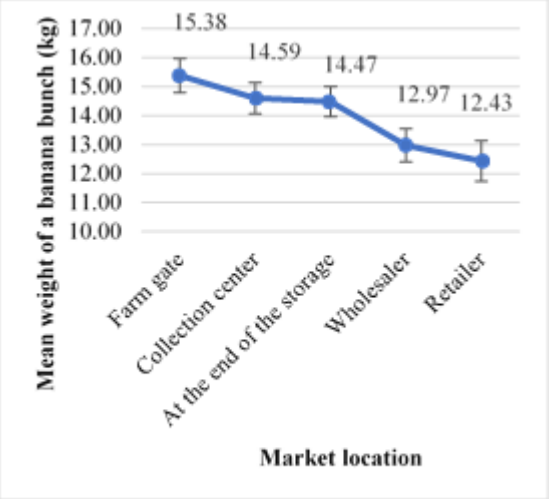

Fig. 1. Mean weight of a banana bunch at each location of the supply chain (kg)

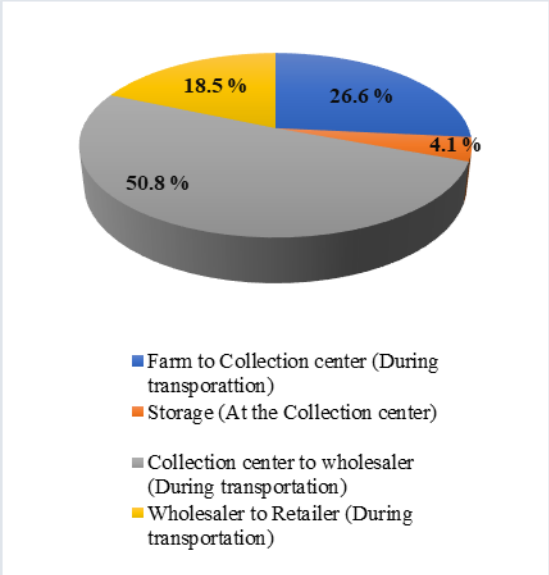

Fig. 2. Weight loss of banana bunches at each location of the supply chain (%)

Network, primarily involving wholesalers, transporters, and retailers in Alawwa town. These key market players were located approximately 7 km away from the Maharacchimulla collection center. Randomly selected six banana bunches (Sour bananas) were tracked throughout the supply chain starting from the farmer fields up until the retailer market and the weight of the bunches was measured at each point. Then the average weight of bunches was calculated to estimate the weight losses. The causes of the weight loss were observed visually and directly through communication with the stakeholders.

3. RESULTS AND DISCUSSION

The Mean Loss Percentage and Standard Deviation were calculated based on the data collected to quantify the losses at different stages of the supply chain. The percentage losses were observed at the following stages:

- Farm gate to Collection center: 0.79 kg (5.14%)
- Collection center to End of storage: 0.12 kg (0.82%)
- End of storage to Wholesaler: 1.50 kg (10.37%)
- Wholesaler to Retailer: 0.54 kg (4.16%)

The Mean Loss Percentage was calculated using the formula:

$$Mean = \sum x^i/n = (5.14+0.82+10.37+4.16)/4 = 5.12\%$$

To assess the variability in loss percentages, the Standard Deviation (SD) was also calculated using the formula:

$$SD = \sqrt{\frac{\sum_{i=1}^{n}(x^i-\bar{x})^2}{n-1}} = 3.96\%$$

This standard deviation value indicates the spread of the data around the mean. A higher standard deviation reflects greater variability in the loss percentages at different stages.

The average loss percentage of 5.12% provides a central value for the losses experienced, while the standard deviation of 3.96% shows that the losses can significantly vary depending on the stage of the supply chain. These calculations provide a clear understanding of the distribution of banana losses throughout the supply chain. According to the current study, the Mean weight loss of banana bunches from the farm gate to the retailer was 20.49%. However, this value is lower than the finding from reference [3], which accounted for 28.5% of the losses and cannot be ignored. This study reveals that the number of stakeholders within the supply chain of bananas in Sri Lanka is higher and that is not a preferable situation.

When there are several stakeholders, the time taken to transport bananas from the farm to the endpoint increases and so do the damages. According to Fig.1 average weight of banana bunches was gradually reduced within the supply chain. Therefore, it is important to observe where those losses occurred and to which degree.

A higher loss occurred during transportation while the bunches were transported from the collection center to the wholesale market (Fig. 2). Similar findings were identified and proven that the total harvest of the cabbage was significantly lost during the transportation period [4]. It was observed that at each point during transportation poor handling caused damage to the fruits. Both loading and unloading of the bunches were done without proper attention. Transportation of the bunches from one location to the other was done by three-wheelers and small Lorrie and because of the long distance, means long distance was related to the poor transportation facilities with connecting poor roads.

Most importantly, starting from the farm gate the bunches were not packed properly (Fig. 3A). There were no cushioning or lining materials between the bunches. This matter coupled with the loaded vehicles during transportation can damage the bunches due to very high impact compression, vibration, bruising, and breakage damages [3, 5].

Also, it could be observed that at most of the places, the whole bunches were packed in bulk and transported. Most of those involved favored using bulk-packed vehicles to transport bananas in whole as complete bunches. The most often cited justifications for this preference included ease of travel and sale, minimal transportation costs, and demand for bunches from both retailers and consumers. Also, they believe that, when the hands are detached from the bunch, they ripen faster than if the bunch is left intact, damage is comparatively higher when handling and simultaneously wilting and weight loss could be higher [3].

However, a considerably lower weight loss could be observed in the storage at the collection center during 48 hours (Fig. 2). Though that was the case the way of storing banana bunches in the storage room was not that much acceptable (Fig. 3B).

Since it is clear where the losses occur in the supply chain of bananas, it is important to search for possible measures to minimize them, though they cannot be completely avoided. To avoid preharvest losses gained at the farm level, disease-free tissue-cultured plants can be introduced. Also, to reduce the loss that occurs due to the excessive production of bananas, the preparation of value-added products such as juice, jams, powders, biscuits, cakes, and baby foods can be mentioned.

Fig. 3. Transportation of banana bunches from the farm gate to the collection market (A), Stored banana bunches (B)

A suitable bulk packing method for transporting entire banana bunches should be introduced. Because a majority of loss has occurred due to poor packaging and handling. Reference [5] has suggested using perforated plastic crates or boxes to handle banana hands during transporting and ripening. In the meantime, ongoing training and awareness programs should be conducted to improve the handling and transportation conditions of bananas and reduce postharvest loss [3]. Government intervention is highly recommended to succeed in these suggested measures. Bruising causes an increase in weight loss and a decrease in color lightness, especially at a higher temperature of 22°C. This implies that bruised bananas lose moisture more rapidly and experience color degradation over time at warmer temperatures. The firmness of bruised bananas decreases as both the storage temperature and impact level increase. Higher temperatures and greater impact result in softer fruit, indicating more extensive damage. Storing bruised bananas at a cooler temperature (13°C) helps to minimize the visible signs of bruising, suggesting that lower temperatures can slow down the effects of mechanical damage, preserving fruit quality for a longer period [6].

Low humidity levels increase moisture loss from bananas, causing weight reduction. Maintaining high humidity (around 90-95%) can minimize this loss.

Some studies confirm that the damage by cutting and abrasion causes a remarkable increase in fresh weight loss of fruits compared to control, even under cold conditions (15 °C) and high relative humidity (89%) [7]. Increased air circulation can exacerbate moisture loss by enhancing evaporation, which leads to weight reduction. Controlled airflow is essential for minimizing this effect. Bananas at different stages of ripeness lose water at varying rates.

Unripe bananas generally lose less weight compared to fully ripened ones due to lower respiration rates.

The type and quality of packaging can influence weight loss. Properly sealed or ventilated packaging can reduce moisture loss and weight reduction.

Post-harvest treatments such as coating, waxing, or the application of certain chemicals can reduce moisture loss and thus prevent weight reduction in banana bunches. Bruised or damaged bananas tend to lose weight more rapidly due to increased respiration and water loss from the damaged areas.

Exposure to ethylene gas accelerates ripening, which can increase respiration and moisture loss, leading to a faster weight reduction. Damage due to impact disrupts the conversion of starch to soluble sugars in the pulp. Damages caused by impact and compression lead to an earlier ethylene production peak. These damages also speed up the fruit ripening process. Impact damage significantly boosts the activity of polyphenol oxidase and peroxidase [7].

4. CONCLUSION

The current study showed that the banana postharvest loss from the farm gate to the retailer market is around 20.49%. Though the obtained value is lower compared to the other studies the losses cannot be ignored. A majority of the losses had occurred during transportation and comparatively a lower loss could be obtained during the 48 hours of storage at the collection center. Since banana is a highly demanding and nutritious fruit within the country, responsible authorities should be able to implement actions to minimize the pointed losses at each location

5. REFERENCES

[1] S. Kamalakkannan, W.M. Wasala, A.K. Kulatunga, C.R. Gunawardena, D.M. Bandara, J. Jayawardana, R.M. Rathnayake, R.M. Wijewardana, W.A. Weerakkody, I. Ferguson, and C. Chandrakumar, "Life cycle assessment of food loss impacts: the case of banana postharvest losses in Sri Lanka," Procedia CIRP, vol.1, pp. 859-864, 2022.

[2] E. Perming, "Paddy and banana cultivation in Sri Lanka: a study analyzing the farmers' constraints in agriculture with a focus on Sooriyawewa DS division," Student thesis series INES, 2014.

[3] W.M. Wasala, D.A. Dharmasena, T.M. Dissanayake, and B.M. Thilakarathne, "Physical and mechanical properties of three commercially grown banana (*Musa acuminata* Colla) cultivars in Sri Lanka," JPHT, vol.2, pp. 80-87, 2014.

[4] H.M.V.T.Jayamal, H.K.S.P. Bandara, A.P.R.T. Pathirana, J.L.t. Madushanka, M.A.P. Madushani, D.T.A.I.T.Y. Dahanayaka, R.M.P.I. Rajapaksha, D.D.N. Vibodhani, R.M.S.M.B. Rathnayaka, "Postharvest losses of Cabbage along the market chain: A case study from Sri Lanka. 3rd International Research Conference Sri Lanka Technology Campus, 2003.

[5] Z. Woldu, A. Mohammed, D. Belew, Z. Shumeta, and A. Bekele, "Assessment of banana postharvest handling practices and losses in Ethiopia," JBAH, vol.5, pp. 82-96, 2015.

[6] Al-Dairi M, Pathare PB, Al-Mahdouri A. The contribution of impact damage to the quality changes of stored banana fruit. InBiology and Life Sciences Forum 2022 Apr 15 (Vol. 16, No. 1, p. 31). MDPI.

[7] Maia VM, Salomão LC, Siqueira DL, Aspiazú I, Maia LC. Physical and metabolic changes induced by mechanical damage in Dwarf-Prata'banana fruits kept under cold storage. Australian Journal of Crop Science. 2014 Jul 1; 8(7):1029-37.

A Review in Morphology, Health Benefits and Propagation Methods of Selected Medicinal Plants in Sri Lanka

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***Abstract*— there has been growing interest in medicinal plants due to their extensive use in traditional medicine and their potential for extracting active compounds used in drug production worldwide. As a tropical country, Sri Lanka boasts a rich diversity of flora and fauna, making it a significant reservoir of medicinal plants ranging from small herbaceous species to large perennial woody trees. Many of these plants, which have long been valued in traditional medicinal practices, are now being cultivated in commercial and home gardens to preserve them and enhance their utilization. However, due to overharvesting in traditional medicine and ongoing deforestation, the populations of these valuable plants are currently under threat. To ensure the sustainable conservation and multiplication of these plants, it is crucial to accurately identify them based on their morphological features and to thoroughly explore their propagation methods. In response to these challenges, various countries have adopted in vitro micropropagation techniques as a means of propagating medicinal plants. Therefore, observing and developing novel propagation techniques is vital for the sustainable conservation of these species. This study aims to evaluate the morphology, health benefits, and propagation methods of commonly grown medicinal plants in Sri Lanka, including *Salacia reticulata* Wight, *Coscinium fenestratum* (Gaertn.) Colebr., *Hemidesmus indicus* (L.) R. Br., *Withania somnifera* (L.) Dunal, and *Celastrus paniculatus* Willd.**

Keywords—Sri Lanka, medicinal plants, health benefits, In vitro propagation

I. INTRODUCTION

Throughout human history, plants have been essential for food, shelter, clothing, fertilizers, flavors, fragrances, transportation, etc. [1]. One important need among them, which cannot be overlooked is the use of plants for health purposes. Because of the identified values of these plants to heal several diseases and disorders of humans and animals, these plants are known as medicinal plants and used since ancient times. Additionally, these plants are essential to the growth of human cultures all across the world [2]. The use of medicinal plants led to the creation of traditional medicine systems worldwide, including Ayurvedic, Unani, Chinese, Tibetan, Native American, Amazonian, and African local systems. These systems are primarily based on plant-based medicine in a local area [3].

Medicinal plants provide affordable healthcare options for the underprivileged in developing countries and serve as health maintenance alternatives for the affluent in industrialized nations. A significant number of people rely on medicinal plant products for treating ailments or maintaining their health, and this trend shows no signs of declining [4]. Different kinds of seeds, roots, leaves, fruits, skins, flowers, rhizomes, and even the entire plant can be utilized as a source of medicine [5] and in contrast to other plant organs, they have a greater therapeutic potential [6]. These plant organs synthesize and retain distinct molecules referred to as active compounds, which exert physiological influences on humans and other animal species. The majority of the medicinal plants' active chemicals are

employed as drugs because they have either direct or indirect therapeutic effects [5]. Among these active compounds alkaloids, terpenoids, phenolics, and numerous other chemicals can be observed [7] and different plants produce different types of these compounds. In Sri Lanka, many medicinal plants have been used as ayurvedic herbs as well as home remedies since ancient times [6]. The use of medicinal plants for herbal preparations is much higher among rural people, and indigenous knowledge of this subject is prevalent in rural areas of Sri Lanka [8]. Sri Lanka has a long-standing history of traditional medicine, spanning several centuries. Its' practice is a fusion of the indigenous medicine system, known as "deshiya chikitsa," as well as the Ayurveda and Siddha systems [9]. On the other hand, most Sri Lankan home gardens have at least a couple of medicinal plants helpful to alleviate diseases. For that, they use 'home remedies/ folk remedies' which are simply defined as untested, readily available drugs or tonics that are taken without a prescription or medical supervision [6] with the objective of healing.

Accurately identifying medicinal plants is essential for their effective use and for preserving cultural heritage [10]. Knowledge of the diverse plant species, along with their identification and conservation, forms a critical foundation in this field. Ensuring that this knowledge is passed on to future generations is vital for maintaining these traditions [11]. Morphological characteristics are crucial for accurately identifying, and characterizing, medicinal plants. Observed plant characteristics are often related to gross morphology or visible aspects [12]. Plant identification relies on various characteristics, including leaves, flowers, bark, seeds, fruits, roots, and stems, as well as factors like height, growing region, and environmental conditions. Many researchers focus primarily on leaves for identification, as they are consistently present and have a two-dimensional structure [13]. In contrast, flowers, fruits, and seeds, which are three-dimensional and only available during specific seasons, are less frequently studied in identifying medicinal plants [14]. Currently, seed morphology is becoming popular for identification purposes [15]. In rural areas, women and children often collect plants from forests without professional training, leading to the misidentification of medicinal herbs. Manufacturing facilities sometimes receive incorrect or substituted plants, and many lack adequate quality control. Local name variations and the challenge of identifying dried plants further complicate the process. These issues can undermine the effectiveness of Ayurvedic treatments and may cause unexpected side effects [16]. Considering all these factors, proper identification of medicinal plants at their harvesting stage can imply as a main importance in the sector.

The medicinal herbs that are not commonly grown in commercial cultivations or home gardens can be found in their natural habitats ranging from dense-canopied, relatively undisturbed tropical forests, to savannas. According to reference [17], there was a strong correlation between the density of medicinal plant species and higher rainfall, higher elevation, deeper, and more acidic soils [17]. It implies that the Wet zone region of Sri Lanka has more affinity to grow more medicinal plants. Even that is the case current forest cover of the country has recorded as 29.2% of the total land area showing a gradual increment of forest degradation. From this available forest cover, unfortunately, a minimal share of forest cover comes from Central Hills and the South-Western parts of the island [18] indicating the potential threat of habitat destruction of medicinal plants. Another issue related to the population density of some medicinal plants grown in Sri Lanka is the intensive harvest of plants from their natural habitats. In particular, in traditional medicine, these plants are required in massive quantities. However, commercial cultivations are not that visible in society therefore people tend to harvest them from the wild [19; 20]. For these reasons, it is essential to study both traditional and modern methods of propagating medicinal plants. Among new technologies, *in vitro* propagation plays a significant role in the cultivation of these plants. *In vitro* propagation techniques can be mentioned as a sustainable way to conserve these valuable medicinal plants which is a proper solution to the above-mentioned issues. According to reference [21], there are three basic groups of experimental methodologies utilized for tissue culture growth of medicinal plants. The most frequent method is to isolate organized meristems such as shoot tips or axillary buds and stimulate them to grow into whole plants which is known as micropropagation. In the second method, adventitious shoots are initiated on leaf, root, and stem segments, as well as callus-derived segments. These organs are derived from them. Induction of somatic embryogenesis in cell and callus cultures is the third mode of propagation. This approach is theoretically the most efficient since once the entire procedure is standardized, a large number of somatic embryos can be obtained [21]. Plant tissue culture offers a more efficient way of propagating and producing secondary metabolites *in vitro*, compared to traditional propagation methods. This approach does not require the sacrifice of plants from their natural habitats and enables large-scale propagation [22]. Numerous studies have been conducted to develop strategies to assist growers in meeting the demands of the pharmaceutical sector in the current world. These protocols are intended to provide optimal levels of growth conditions required to achieve high regeneration rates *in vitro* of many plant species and thus facilitate commercially viable micropropagation.

The medicinal plants selected for this review are well-known in Sri Lankan society for their numerous health benefits. It is essential to accurately identify their morphology and gain a more thorough understanding of their propagation methods

A. Salacia reticulata Wight.

This large woody climbing shrub belongs to the family Celastraceae [23] and in Sinhala, it is known as '*Kothala Himbutu'* [24]. Greenish gray bark is smooth and the opposing leaves are elliptic-oblong, with an acute base and an abruptly acuminate apex. The edge is serrated with tiny, rounded teeth, and the lateral nerves, which are about seven pairs and conspicuous beneath, are leathery, hairless,

and shining. Leaf dimensions range from 3-6 inches long and 1-2 inches wide [25]. It develops clusters of 2–8 flowers that range in color from greenish white to greenish yellow in the axils of the leaves [26]. Big, tuberculate fruits are vividly pinkish-orange, and the seeds can be seen in the fruit pulp [23].

The bark of *S. reticulata* is said to be helpful when used orally in the relief of diabetes, gonorrhea, problems with the skin, and rheumatism [27]. When it comes to diabetes it is considered a good anti-diabetic medicine, especially in traditional medicine and it is patented as having the ability to make anti-diabetic medications [28]. Salacinol, a highly effective α-glucosidase inhibitor, has been isolated from this plant. Salacinol exhibited substantial inhibitory activities on many α-glucosidases, including maltase, sucrase, and isomaltase. It was also discovered that its' inhibitory effects on serum glucose levels in maltose and sucrose were stronger than those of the commercial α-glucosidase inhibitor acarbose when tested with rats [24]. Furthermore, Mangiferin in *S. reticulata* acts straight on liver cells and controls the production of fructose-1,6-bisphosphatase, which inhibits the gluconeogenic pathway and lowers fasting blood glucose levels [29].

In this plant, a minimal fraction of seeds germinate, and it takes a very long period to do so [23]. However, it is possible to draw the conclusion that *S. reticulata* can be vegetatively propagated with a range of efficacy. Also, this plant can be successfully propagated vegetatively when semi-hardwood stem cuttings are planted in topsoil: compost (1:1) [20]. For sustainable leaf and stem harvesting bushy-type plants can be maintained by proper pruning while adding T200; the fertilizer recommendation for young tea plantations (N: P_2O_5: K_2O - 100kg: 50Kg: 25Kg) at a rate of 175 Kg/ha [30].

B. Coscinium fenestratum (Gaertn.) Colebr.

In Sinhala *Coscinium fenestratum* is known as '*Weniwelgeta*' and it is a perennial, native, woody climber plant. It belongs to the family Menispermaceae and is commonly known as Tree turmeric. In Sri Lanka and India's Western Ghats, it is a common plant however considered a very rare medicinal liana [31]. *C. fenestratum* has distinct male and female plants. Young stems and branches have a yellow color bark which is densely pubescent, very rarely with slender tendrilled branchlets. Leaves are simple, alternate and thick with entire margins and size ranges from 13 to 30 cm in to 12 to 23 cm. The flower cluster is located above the axis and covered in fine hair. Male flowers are round and densely packed, measuring 6 mm in diameter. Female flowers are hairy, with reflexed, filiform styles. The female fruiting peduncles are 2-3cm long, and the drupes are around 1 to 3 [32].

Coscinium fenestratum has mostly been utilized to treat diabetes mellitus in the conventional Ayurvedic and Siddha medical systems. The plant has primarily been used to treat diabetes mellitus and is frequently recommended as an active ingredient for a variety of medicinal goals [33]. According to ethnomedicine, the stem of *C. fenestratum* can be applied as a poultice to heal wounds, sores, piles, fever, jaundice, and other conditions [34; 35]. The plant is used to treat inflammations, ophthalmopathy, and general debility and is said to have thermogenic, anti-inflammatory, antiseptic, and tonic effects [36]. The *C. fenestratum* root has multiple uses as a bitter tonic, stomachic, antibacterial agent, and dressing for wounds and ulcers. It's also an effective treatment for dysentery. The stem bark decoction is known to cure intermitpalmata, while the wood is a bitter tonic and can be used as a substitute for calumba [37]. The decoction of the stem is beneficial for treating persistent fevers [38]. In the traditional techniques of treating herpes in coastal Karnataka, India, this plant is utilized as a single herb as well as in combination with other therapeutic herbs [39].

Seeds and vegetative perennial stem cuttings are the two primary methods of natural propagation of this plant. Vegetative reproduction moves very slowly, and traditional methods of propagation of seeds and vegetative cuttings are insufficient to satisfy the needs for preservation and long-term utilization [40; 41].

C. Hemidesmus indicus (L.) R. Br.

This highly valued medicinal plant belongs to the family Apocynaceae [42] and in Sri Lanka commonly known as 'Ira Musu' is considered a wild plant species [19]. This perennial, fast-growing, prostrate, or semi-erect shrub is twining and wiry while having a strong, woody, and tuberous rootstock [19; 43; 44]. Their branches are laticiferous and the bark is purplish [42]. Comparatively larger upper leaves are dark green and not variegated, while the narrower lower leaves are frequently variegated with white lines above [44].

Hemidesmus indicus has an extended record of medicinal use in the conventional system of medicine dating back to the past because of its wide range of pharmacological action due to its diversified phytochemical makeup [42]. It is among the herbs that are utilized in Ayurveda treatments for chronic rheumatism, kidney problems, syphilis, and tonicity including demulcent, diaphoretic, diuretic, and alternative medicine [43]. In Sri Lanka, the leaves are used to produce a paste or herbal beverages. Most frequently, this plant is given as treatment for leukemia, breast, uterine, and liver cancers [9]. For snake bites, it has also been used in conjunction with other medications. Additionally, this herb was utilized to cure hemotoxic viper venom that caused mortality [45]. Aqueous extraction of roots mainly contains Tannins and Saponins and possesses antibacterial activity against pathogenic bacteria [46]. Meantime roots have an antifungal effect [47], and through the inhibition of intestinal motility and its bacteriocidal activity, it may have an antidiarrheal effect [48]. According to [45], this plant possesses an extensive range of antioxidant, anticoagulant, hypolipidaemic, antiplatelet aggregation, anti-hemorrhagic, and lipoprotein lipase-releasing characteristics, making it a potent antiatherogenic agent that helps prevent coronary artery disorders. Also, it has been found that tannins and other

phenolic components, such as hemidesmin 1 and hemidesmin 2, as well as 2-hydroxy-4-methoxy benzoic acid, which has been demonstrated to possess antioxidant qualities, are responsible for the antioxidant action of this plant [49].

Plants are traditionally propagated through seed germination or vegetative propagation, but the efficacy of these methods has some limitations. Because some plants grown from seed germination are susceptible to seed-borne illnesses, plantlet output through vegetative propagation is also not sufficient [22].

D. Withania somnifera (L.) Dunal

This perennial shrub belongs to the family Solanaceae known in Sinhala as 'Amukkara' and has been recognized for its valuable medicinal properties since ancient times [50; 51]. It usually reaches a height of around 1 to 2 m and nearly the entire plant is coated and encircled by very tiny, branching silver-grey hairs. [51; 52]. Flowers are smaller in size, green in color and the fruit is mature when it is orange-red in color and contains milk-coagulating characteristics [53].

Most of the organs of *W. somnifera* have enriched with a number of chemicals with medicinal properties including Alkaloids, Flavonoids, Iso-flavonoids, Phenols, Nitrogen-containing compounds, Salts, Steroids, and Steroidal lactones [54; 55]. Due to their abundance of medicinal substances, the roots are regarded as the primary components of the entire plant. It activates immune system components including lymphocytes and phagocytes, which work to reduce the negative effects of stress and overall support health. Though the root is considered the major part to be used in traditional medicines other parts of the plants also can be used [54]. For instance, Withaferin A, which is a potential anti-cancer agent can be widely found in the leaves and bark of *W. somnifera* [50]. *W. somnifera* is beneficial for the entire body and can be taken orally or as a tonic. Among its health benefits ability to guard against the swelling and cartilage damage brought on by osteoarthritis, antianxiety effects, reduction of blood sugar and cholesterol levels with regular use, and reduce inflammation which may be common in overweight people can be very important [53].

In Sri Lanka, there are mainly two cultivars of *W. somnifera* known as Local and Indian [52], and they can be found in cultivations under small-scale production [50]. Usually, seeds are used to propagate *W. somnifera*, but a substance found in the fruit wall inhibits seed germination and over a period of time the percentage of seeds that germinate dramatically declines [56].

E. Celastrus paniculatus Willd

Commonly this plant is known as Black Oil and in Sinhala identified as '*Duhudhu*'. It is a perennial, native plant and an unarmed large woody climber which reaches up to 10 m in height. Alternately arranged leaves are very variable - elliptic, ovate, broadly obovate, or circular, and the length ranges from 6 to 10 cm while the width is around 3 to 6 cm. The inflorescence has a panicle structure, with yellowish or greenish-white flowers. The capsule has a diameter of 9-12 mm and is a bright yellow color. It is transversely wrinkled and has three valves that spread apart when it opens. The valves remain united at the base, revealing the seeds inside [57].

In accordance with Ayurveda, *Celastrus paniculatus* may be used as a stimulant, nerve tonic, rejuvenant, sedative, tranquilizer, and diuretic, depending on the dosage regimen. It can be used in the treatment of rheumatism, gout, leprosy, leucoderma, paralysis, and asthma diseases [58; 59]. It is also considered as better a treatment for mental diseases, therefore decoction of the root or seed internally can be used, as a brain tonic for headaches, depression, and swooning and as a laxative for cleaning the digestive system. Internal use of seed oil in neurological disorders, urinary infections, skin affections, and intestinal parasites externally for wound healing, and the leaf juice was also given in opium poisoning as a deaddiction aid and as a laxative [60]. In Indian ayurvedic medicine, *C. paniculatus* is used for the treatment of cough and leucoderma and it was also given as an appetizer, laxative, emetic, and aphrodisiac. The bark of this plant has the ability to induce abortion, so it has been used for that purpose. It is one of the components of the drug called "Mentat syrup" that has been prescribed for mental illnesses. This has a long history of usage in traditional medicine, where it is recognized to have brain-stimulating and antioxidant effects. In China, it is also used as an important medicine to treat fever, joint pain, swelling, rheumatoid arthritis, and bacterial infection, and *C. paniculatus* plant is also used as a natural insecticide [61; 62].

In Sri Lanka, these species are extremely few live specimens are to be discovered. The scientific study of conservation and commercial cultivation of this species of plant, is essential. Due to the seeds' extremely low viability and low percentage of germination, this plant's natural propagation is weak [63]. Although *C. paniculatus* may be transmitted by seeds, the proportion of seeds that actually germinate is relatively low because of inhibitory substances found in the seed coat. Even cuttings cannot root successfully [56].

In vitro micropropagation of medicinal plants

There are two ways to propagate plants: sexually and asexually. Sexual propagation involves the fusion of zygotic embryos that come from the parent gametes within the seeds or fruits, resulting in new plants. On the other hand, the vegetative (asexual) cycle is typically used to conserve the unique traits of a particular plant selected for propagation [64]. However, compared to other conventional vegetative propagation methods, *in vitro* micropropagation techniques are more advanced due to several reasons such as the production of disease-free plants, precise control of the growing environment, rapid production of clones, year-round production, and requirement of lesser space.

Micropropagation is a process in which a specific genotype is propagated using *in vitro* culture techniques, ensuring that the resulting plants are genetically identical to the original plant [65]. Basically, in a micropropagation cycle there are five stages known as, mother plant selection and preparation, establishing an aseptic culture, the production of suitable propagules, preparation for growth in the natural environment and transfer to the natural environment [64]. Procedures in each step vary between plant species and the type of explant that is used.

The population of medicinal plants in Sri Lanka is currently in danger due to different reasons. When we observe the conservation efforts of other countries for endangered medicinal and other plant species, they often utilize sustainable *in vitro* propagation techniques to preserve the genetic material and boost population numbers. Several scientists have conducted several studies about the micropropagation of many plant species, including many therapeutic herbs (Table I). Micropropagation of medicinal plants has been accomplished in culture through fast multiplication of shoot tips and axillary buds. Numerous factors have been documented to influence the efficacy of *in vitro* propagation of various medicinal plants also [21]. Table 1, shows some *in vitro* propagation protocols investigated to propagate above mentioned medicinal plants.

II. CONCLUSION

Sri Lanka is home to immense biodiversity, with medicinal plants playing a significant role. Globally, medicinal plants are integral to traditional medicinal systems and are widely used in drug preparation due to their ability to treat various human illnesses. However, the populations of these plants are not at optimal levels, making it crucial to accurately identify them and explore new methods for their propagation. This review highlights five important medicinal plants growing in Sri Lanka and their major health benefits mainly including controlling diabetes, cancers, and mental illnesses. Given the current threats to their populations, it is vital to focus on effective propagation strategies. In this context, *in vitro* propagation offers significant potential and numerous advantages for the sustainable conservation and multiplication of these valuable plants

Table I: Different types of *In vitro* propagation protocols available for the propagation of each medicinal plant.

Plant Species	Type of explant	Culture media	Citation
1. *Salacia reticulata*	Nodal segments	● Shoot multiplication- MS medium supplemented with BAP and IAA (3.5 + 0.5 mg/L). ● Subculture every 20 days. ● *In vitro* rooting- On half-strength MS supplemented with IBA (2.0 mg/L).	[23]
	Leaf segments	● Callus initiation- MS supplemented with 4 mg/L 2,4-D and 3 mg/L TDZ.	[26]
2. *Coscinium fenestratum*	Epicotyl segments (from 20 days old *in vitro* germinated seedlings on MS medium supplemented with 3% sucrose and 0.8% agar)	● Shoot initiation- MS medium supplemented with 1.0 µM Kinetin and 0.25 µM 2,4-D. ● *In vitro* rooting- Half-strength MS supplemented with 2.5 µM IBA. ● Acclimatization- In pots with compost and sand for 12 days and then transfer to compost beds for 2 months.	[41]
	Mature double nodal cuttings	● Shoot proliferation- Woody Plant Medium (WPM) + 1.0 mg/L PVP supplemented with 0.4 mg/L 2,4-D, 2.0 mg/L of BAP and 1.0 mg/L TDZ. ● Acclimatization- On coir dust and compost (1:1)	[66]
3. *Hemidesmus indicus*	4th and 5th nodal segments	● For multiplication MS medium supplemented with 2 mg/L BAP and 0.1 mg/L NAA. ● *In vitro* rooting- With half-strength MS supplemented 1.5 mg/L IBA ● Acclimatization- On sterile soil and sand (1:3) medium.	[19]

	Buds	● For bud multiplication MS medium supplemented with 0.1 mg/L NAA and 2.0 mg/L BAP ● *In vitro* rooting- With half-strength MS medium supplemented with 1.5 mg/L IBA ● Acclimatization- On sterile soil	[67]
4. Withania somnifera	Shoot tips and Nodes	● MS medium supplemented with 1.0 µM kinetin, 4.5 µM BAP, and 1.5 µM NAA within a 14-day dark period.	[56]
5. Celastrus paniculatus Willd	Fully opened second leaf	● Callus initiation- MS medium supplemented with 0.5 mg/L BAP with 0.5 mg/L NAA within a 16/8 hours light/dark regimes.	[68]

(Abbreviations: MS- Murashige and Skoog medium, BAP- 6-Benzylaminopurine, IAA- Indole-3-acetic acid, IBA- Indole-3-butyric acid, 2,4-D- 2,4-dichlorophenoxyacetic acid, TDZ- Thidiazuron, PVP- Polyvinylpyrrolidone, NAA- 1-Naphthaleneacetic acid)

REFERENCES

[1] A. Gurib-Fakim, "Medicinal plants: traditions of yesterday and drugs of tomorrow," *Molecular Aspects of Medicine*, vol. 27, no. 1, pp. 1-93, Jan. 2006. DOI: 10.1016/j.mam.2005.07.008.

[2] B. A. Rasool Hassan, "Medicinal plants (importance and uses)," *Pharmaceutica Analytica Acta*, vol. 3, no. 10, p. 1, Oct. 2012. DOI: 10.4172/2153-2435.1000e139.

[3] N. Mamedov, "Medicinal plants studies: History, challenges and prospective," *Medicinal and Aromatic Plants*, vol. 1, no. 8, p. e133, Aug. 2012. DOI: 10.4172/2167-0412.1000e133.

[4] C. Smith-Hall, H. O. Larsen, and M. Pouliot, "People, plants and health: a conceptual framework for assessing changes in medicinal plant consumption," *Journal of Ethnobiology and Ethnomedicine*, vol. 8, pp. 1-11, Jan. 2012.

[5] F. Jamshidi-Kia, Z. Lorigooini, and H. Amini-Khoei, "Medicinal plants: Past history and future perspective," *Journal of Herbmed Pharmacology*, vol. 7, no. 1, pp. 1-7, Jan. 2017. DOI: 10.15171/jhp.2018.01.

[6] M. K. P. N. Mirihagalla and K. M. C. Fernando, "Medicinal plants use for home remedies in Sri Lanka: A Review," *International Journal of Minor Fruits, Medicinal and Aromatic Plants*, vol. 7, no. 2, pp. 29-39, Jun. 2021.

[7] M. Daniel, *Medicinal plants: chemistry and properties*. Enfield, NH, USA: Science Publishers, 2006.

[8] M. T. Napagoda, T. Sundarapperuma, D. Fonseka, S. Amarasiri, and P. Gunaratna, "Traditional uses of medicinal plants in Polonnaruwa district in North Central Province of Sri Lanka," *Scientifica*, vol. 2019, pp. 1-11, 2019. DOI: 10.1155/2019/9737302.

[9] A. I. Kuruppu, P. Paranagama, and C. L. Goonasekara, "Medicinal plants commonly used against cancer in traditional medicine formulae in Sri Lanka," *Saudi Pharmaceutical Journal*, vol. 27, no. 4, pp. 565-573, Jul. 2019. DOI: 10.1016/j.jsps.2019.02.004.

[10] P. Sillitoe, "The state of indigenous knowledge in Bangladesh," in *Indigenous Knowledge Development in Bangladesh: Present and Future*, P. Sillitoe, Ed. London: Intermediate Technology Publications, 2000, pp. 3-23.

[11] H. Yazdanshenas, S. A. Mousavi, A. Tavili, and E. Shafeian, "Identification of medicinal plants based on modern and indigenous knowledge (case study: Ghasem Abad rangeland, west of Isfahan province, Iran)," *Rep. Opin.*, vol. 8, no. 2, pp. 1-8, Feb. 2016.

[12] H. Fazal, N. Ahmad, and B. Haider Abbasi, "Identification, characterization, and palynology of high‐valued medicinal plants," *The Scientific World Journal*, vol. 2013, p. 283484, 2013.

[13] S. Kumar, "Leaf color, area and edge features based approach for identification of Indian medicinal plants," *International Journal of Computer Science and Engineering*, vol. 3, no. 3, pp. 436-442, Mar. 2012.

[14] S. Rajani and M. N. Veena, "Study on identification and classification of medicinal plants," *International Journal of Advances in Science Engineering and Technology*, vol. 6, no. 2, pp. 13-18, 2018.

[15] M. Hani, M. Merghem, and R. Lebazda, "Identification of medicinal plants on the basis of morphological observation of seeds in the region of Sétif, Algeria," *Asian Journal of Biological and Life Sciences*, vol. 10, pp. 687-694, 2021.

[16] P. M. Manojumar, C. M. Surya, and V. P. Gopi, "Identification of ayurvedic medicinal plants by image processing of leaf samples," in *Proc. 2017 Third International Conference on Research in Computational Intelligence and Communication Networks (ICRCICN)*, Nov. 2017, pp. 231-238. DOI: 10.1109/ICRCICN.2017.8234484.

[17] J. Russell-Smith, N. S. Karunaratne, and R. Mahindapala, "Rapid inventory of wild medicinal plant populations in Sri Lanka," *Biological Conservation*, vol. 132, no. 1, pp. 22-32, May 2006. DOI: 10.1016/j.biocon.2006.03.009.

[18] K. T. Premakantha, R. P. D. S. Chandani, S. A. D. Kingsly, H. U. Dias, and N. S. B. Kekulandara, "Forest cover assessment in Sri Lanka using high resolution satellite images," *The Sri Lanka Forester*, vol. 40, pp. 01-16, Jun. 2021.

[19] D. S. K. Nagahatenna and S. E. Peiris, "In vitro propagation of *Hemidesmus indicus* (L.) R. Br. (Iramusu) through nodal culture," *Tropical Agricultural Research*, vol. 19, pp. 181-192, 2007.

[20] E. K. E. Nayana, S. Subasinghe, K. K. I. U. Arunakumara, M. K. T. K. Amarasinghe, and H. K. M. S. Kumarasinghe, "Effect of maturity and potting media on vegetative propagation of *Salacia reticulata* (Kothalahimbatu) through stem cuttings," *International Journal of Minor Fruits, Medicinal and Aromatic Plants*, vol. 1, no. 1, pp. 47-54, 2015. Available: http://ir.lib.ruh.ac.lk/xmlui/handle/iruor/11210.

[21] G. R. Rout, S. Samantaray, and P. Das, "In vitro manipulation and propagation of medicinal plants," *Biotechnology Advances*, vol. 18, no. 2, pp. 91-120, Mar. 2000. DOI: 10.1016/S0734-9750(99)00026-9.

[22] M. M. Kher, M. S. Shekhawat, M. Nataraj, and J. A. Teixeira da Silva, "Indian sarsaparilla, *Hemidesmus indicus* (L.) R. Br. ex Schult: Tissue culture studies," *Applied Microbiology and Biotechnology*, vol. 104, pp. 6463-6479, Aug. 2020. DOI: 10.1007/s00253-020-10714-9.

[23] G. Dhanasri, M. S. Reddy, B. Naresh, and D. Cherku, "Micropropagation of *Salacia reticulata*—an endangered medicinal plant," *Plant Tissue Culture and Biotechnology*, vol. 23, no. 2, pp. 221-229, 2013.

[24] M. Yoshikawa, T. Morikawa, H. Matsuda, G. Tanabe, and O. Muraoka, "Absolute stereostructure of potent α-glucosidase inhibitor, salacinol, with unique thiosugar sulfonium sulfate inner salt structure from *Salacia reticulata*," *Bioorganic & Medicinal Chemistry*, vol. 10, no. 5, pp. 1547-1554, May 2002. DOI: 10.1016/S0968-0896(01)00422-9.

[25] K. K. I. U. Arunakumara and S. Subasinghe, "Salacia reticulata Wight: A review of botany, phytochemistry and pharmacology," *International Journal of Minor Fruits, Medicinal and Aromatic Plants*, vol. 1, no. 1, pp. 47-54, 2010.

[26] K. Dias, N. Kottearachchi, A. Chandrasekara, and A. N. De Silva, Eds., "Antioxidant analysis and in vitro culture establishment of *Kothala Himbutu* (*Salacia reticulata*)," in *Proceedings of the 14th Agricultural Research Symposium*, 2015.

[27] Y. Sekiguchi, H. Mano, S. Nakatani, J. Shimizu, and M. Wada, "Effects of the Sri Lankan medicinal plant, *Salacia reticulata*, in rheumatoid arthritis," *Genes & Nutrition*, vol. 5, no. 1, pp. 89-96, Mar. 2010. DOI: 10.1007/s12263-009-0144-3.

[28] D. K. N. G. Pushpakumara, H. B. Kotagama, B. Marambe, G. Gamage, K. A. I. D. Silva, L. H. P. Gunaratna, C. Wijesundara, and S. S. D. K. Karaluvinne, "Prospects of pharmaceutical prospecting to finance biodiversity conservation in Sri Lanka," *Sri Lankan Journal of Agricultural Economics*, vol. 4, pp. 39-71, 2002.

[29] R. Im, H. Mano, T. Matsuura, S. Nakatani, J. Shimizu, and M. Wada, "Mechanisms of blood glucose-lowering effect of aqueous extract from stems of Kothala himbutu (*Salacia reticulata*) in the mouse," *Journal of Ethnopharmacology*, vol. 121, no. 2, pp. 234-240, 2009. https://doi.org/10.1016/j.jep.2008.10.026.

[30] R. M. S. M. B. Rathnayaka and S. Subasinghe, "Development of bushy type Kothala Himbutu (*Salacia reticulata* White) plantation for sustainable leaf/stem harvesting," in *Proceedings of the 8th Academic Sessions, University of Ruhuna 2010*, University of Ruhuna, 2011. Available: http://ir.lib.ruh.ac.lk/xmlui/handle/iruor/6214.

[31] K. V. Tushar, S. George, A. B. Remashree, and I. Balachandran, "*Coscinium fenestratum* (Gaertn.) Colebr. - a review on this rare, critically endangered and highly-traded medicinal species," *Journal of Plant Science*, vol. 3, pp. 133-145, 2008. https://doi.org/10.3923/jps.2008.133.145.

[32] V. Danapur, C. Haleshi, and A. N. Sringeswara, "Endangered medicinal plant *Coscinium fenestratum* (Gaertn.) Colebr. A Review," *Pharmacognosy Journal*, vol. 12, no. 5, 2020. http://dx.doi.org/10.5530/pj.2020.12.152.

[33] R. Watthanachaiyingcharoen, K. Komatsu, S. Zhu, O. Vajragupta, and W. Leelamanit, "Authentication of *Coscinium fenestratum* among the other Menispermaceae plants prescribed in Thai folk medicines," *Biological & Pharmaceutical Bulletin*, vol. 33, no. 1, pp. 91-94, 2010. https://doi.org/10.1248/bpb.33.91.

[34] N. Eswani, K. Abd Kudus, M. Nazre, A. A. Noor, and M. Ali, "Medicinal plant diversity and vegetation analysis of logged over hill forest of Tekai Tembeling Forest Reserve, Jerantut, Pahang," *Journal of Agricultural Science*, vol. 2, no. 3, p. 189, 2010.

[35] S. J. Sudharshan, T. R. P. Kekuda, and M. L. Sujatha, "Antiinflammatory activity of *Curcuma aromatica* Salisb and *Coscinium fenestratum* Colebr: a comparative study," *Journal of Pharmacy Research*, vol. 3, no. 1, pp. 24-25, 2010.

[36] K. Chitra, K. Sujatha, H. Polisetti, S. Karri, and C. U. Reddy, "Standardization of *Coscinium fenestratum* with reference to berberine by high performance thin layer chromatography," *Journal of Pharmacy Research*, vol. 3, no. 1, pp. 24-25, 2011.

[37] R. Siva, "Status of natural dyes and dye-yielding plants in India," *Current Science*, vol. 92, no. 7, pp. 916-925, 2007. Available: https://www.jstor.org/stable/24097672.

[38] A. B. D. Selvam, "Is the term substitution relevant to Pharmacognosy and/or vegetable crude drug industry?"

Pharmacognosy Research, vol. 2, no. 5, p. 323, 2010. https://doi.org/10.4103/0974-8490.72333.

[39] M. J. Bhandary and K. R. Chandrashekar, "Herbal therapy for herpes in the ethno-medicine of Coastal Karnataka," *Indian Journal of Traditional Knowledge*, vol. 10, no. 3, pp. 528-532, 2011. Available: http://indianmedicine.eldoc.ub.rug.nl/id/eprint/64534.

[40] S. Kashyap, N. Kapoor, and R. D. Kale, "*Coscinium fenestratum*: Callus and suspension cell culture of the endangered medicinal plant using vermicompost extract and coelomic fluid as plant tissue culture media," *American Journal of Plant Sciences*, vol. 7, no. 6, p. 899, 2016.

[41] W. T. P. S. K. Senarath, "In vitro propagation of *Coscinium fenestratum* (Gaertn.) Colebr. (Menispermaceae)-an endangered medicinal plant," *Journal of the National Science Foundation of Sri Lanka*, vol. 38, no. 4, pp. 219-223, 2010. Available: http://dr.lib.sjp.ac.lk/handle/123456789/900.

[42] H. Moorthy and V. Kumar, "Hemidesmus indicus (L.) R. BR.: An overview," *Plant Archives*, vol. 21, no. 1, pp. 2132-2143, 2021. https://doi.org/10.51470/PLANTARCHIVES.2021.v21.S1.352.

[43] V. Aneja, A. Suthar, S. Verma, and S. Kalkunte, "Phyto-pharmacology of *Hemidesmus indicus*," *Pharmacognosy Reviews*, vol. 2, no. 3, p. 143, 2008.

[44] S. Nandy, A. Mukherjee, D. K. Pandey, P. Ray, and A. Dey, "Indian Sarsaparilla (*Hemidesmus indicus*): Recent progress in research on ethnobotany, phytochemistry and pharmacology," *Journal of Ethnopharmacology*, vol. 254, p. 112609, 2020. https://doi.org/10.1016/j.jep.2020.112609.

[45] N. K. Mary, C. R. Achuthan, B. H. Babu, and J. Padikkala, "In vitro antioxidant and antithrombotic activity of *Hemidesmus indicus* (L) R. Br," *Journal of Ethnopharmacology*, vol. 87, no. 2-3, pp. 187-191, 2003.

[46] M. Gayathri and K. Kannabiran, "Antimicrobial activity of *Hemidesmus indicus, Ficus bengalensis* and *Pterocarpus marsupium* roxb," *Indian Journal of Pharmaceutical Sciences*, vol. 71, no. 5, pp. 578-581, 2009, doi: 10.4103%2F0250-474X.58182.

[47] S. P. Hiremath, K. Rudresh, and S. Badami, "Antimicrobial activity of various extracts of *Striga sulphurea* and *Hemidesmus indicus*," *Indian Journal of Pharmaceutical Sciences*, vol. 59, no. 3, pp. 145-147, 1997. [Online]. Available: http://gukir.inflibnet.ac.in:8080/jspui/handle/123456789/5435.

[48] S. Das, R. Prakash, and S. N. Devaraj, "Antidiarrhoeal effects of methanolic root extract of *Hemidesmus indicus* (Indian sarsaparilla)-an in vitro and in vivo study," *Indian Journal of Experimental Biology*, vol. 41, pp. 363-366, 2003.

[49] M. N. Ravishankara, N. Shrivastava, H. Padh, and M. Rajani, "Evaluation of antioxidant properties of root bark of *Hemidesmus indicus* R. Br.(Anantmul)," *Phytomedicine*, vol. 9, no. 2, pp. 153-160, 2002.

[50] A. S. Siriwardane, R. M. Dharmadasa, and K. Samarasinghe, "Distribution of withaferin A, an anticancer potential agent, in different parts of two varieties of *Withania somnifera* (L.) Dunal. grown in Sri Lanka," *Pakistan Journal of Biological Sciences*, vol. 16, no. 3, pp. 141-144, 2013, doi: 10.3923/pjbs.2013.141.144.

[51] N. Gaurav, A. Kumar, M. Tyagi, D. Kumar, U. K. Chauhan, and A. P. Singh, "Morphology of *Withania somnifera* (distribution, morphology, phytosociology of *Withania somnifera* L. Dunal)," *International Journal of Current Science Research and Review*, vol. 1, no. 7, pp. 164-173, 2015.

[52] S. Shanmugaratnam, G. Mikunthan, and S. Thurairatnam, "Potential of *Withania somnifera* Dunal cultivation as a medicinal crop in Jaffna district," *American-Eurasian Journal Agriculture and Environment Science*, vol. 13, no. 3, pp. 357-361, 2013, doi: 10.5829/idosi.aejaes.2013.13.03.1941.

[53] M. Umadevi et al., "Traditional and medicinal uses of *Withania somnifera*," *The Pharma Innovation*, vol. 1, no. 9, p. 102, 2012.

[54] P. K. Kumar, M. Swarnalakshmi, and M. Sivanandham, "Phytochemical analysis of *Boerhaavia diffusa, Emblica officinalis, Terminilia chebula, Terminilia bellirica, Withania somnifera*," *World Journal of Pharmaceutical Research*, vol. 4, no. 5, pp. 1747-1756, 2015.

[55] J. M. Macharia, Z. Káposztás, and R. L. Bence, "Medicinal characteristics of *Withania somnifera* L. in colorectal cancer management," *Pharmaceuticals*, vol. 16, no. 7, p. 915, 2023, doi: 10.3390/ph16070915.

[56] M. A. N. De Silva and W. T. P. S. K. Senarath, "In vitro mass propagation and greenhouse establishment of *Withania somnifera* (L.) Dunal (Solanaceae) and comparison of growth and chemical compounds of tissue cultured and seed raised plants," *Journal of the National Science Foundation of Sri Lanka*, vol. 37, no. 4, 2009. [Online]. Available: http://dr.lib.sjp.ac.lk/handle/123456789/903.

[57] M. Younus, "Ethnobotanical study and traditional uses of *Celastrus paniculatus*," *International Journal of Innovative Science Engineering and Technology*, vol. 2, no. 11, pp. 139-143, 2015.

[58] H. Singh, G. Krishna, and P. K. Baske, "Plants used in the treatment of joint diseases (rheumatism, arthritis, gout and lumbago) in Mayurbhanj district of Odisha, India," *Report and Opinion*, vol. 2, no. 9, pp. 22-26, 2010.

[59] M. Gattu, K. L. Boss, A. V. Terry Jr, and J. J. Buccafusco, "Reversal of scopolamine-induced deficits in navigational memory performance by the seed oil of *Celastrus paniculatus*," *Pharmacology Biochemistry and*

Behavior, vol. 57, no. 4, pp. 793-799, 1997, doi: 10.1016/S0091-3057(96)00391-7.

[60] K. A. Deodhar and N. W. Shinde, "*Celastrus paniculatus*: Traditional uses and ethnobotanical study," *Indian Journal of Advances in Plant Research*, vol. 2, no. 1, pp. 18-21, 2015.

[61] P. D. Chen and J. Y. Liang, "Progress of studies on constituents & activities of genus Celastrus," *Strait Pharmaceutical Journal*, vol. 11, no. 3, 1999.

[62] N. Wakabayashi et al., "Celangulin: a nonalkaloidal insect antifeedant from Chinese bittersweet, *Celastrus angulatus*," *Journal of Natural Products*, vol. 51, no. 3, pp. 537-542, 1988, doi: 10.1021/np50057a014.

[63] V. Arya, R. P. Singh, and S. N. Shekhawat, "A micropropagation protocol for mass multiplication and off-site conservation of *Celastrus paniculatus* - a vulnerable medicinal plant of India," *Journal of Sustainable Forestry*, vol. 14, no. 1, pp. 107-120, 2001, doi: 10.1300/J091v14n01_06.

[64] E. F. George and P. C. Debergh, "Micropropagation: Uses and methods," in *Plant Propagation by Tissue Culture: Volume 1. The Background*, E. F. George, M. A. Hall, and G. J. De Klerk, Eds. Springer, 2008, pp. 29-64.

[65] P. C. Debergh and P. E. Read, "Micropropagation," in *Micropropagation*, P. C. Debergh and R. H. Zimmerman, Eds. Springer, 1991, pp. 1-21. https://doi.org/10.1007/978-94-009-2075-0_1

[66] P. S. Warakagoda, S. Subasinghe, and M. T. K. Gunasekare, "In vitro clonal propagation of *Coscinium fenestratum* (Gertn.) Colebr. (Weniwel) through nodal explants," *Journal of the National Science Foundation of Sri Lanka*, vol. 45, no. 2, pp. 133-141, 2017.

[67] S. Saha, M. J. Mukhopadhyay, and S. Mukhopadhyay, "In Vitro Clonal Propagation Through Bud Culture of *Hemidesmus indicus* (L) R Br: An Important Medicinal Herb," *Journal of Plant Biochemistry and Biotechnology*, vol. 12, pp. 61–64, 2003. https://doi.org/10.1007/BF03263162

[68] A. K. Moola and B. D. R. Kumari, "Rapid propagation of *Celastrus paniculatus* Willd: An endangered medicinal plant through indirect organogenesis," *Vegetos*, vol. 33, no. 2, pp. 277–285, 2020. https://doi.org/10.1007/s42535-020-00105-w

A Review of the Role of Soil Microbiomes in Enhancing Crop Productivity

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Abstract— **Soil is an essential component of the ecosystem, supporting terrestrial living forms. Healthy soil promotes the functioning of ecosystem services by improving the condition of flora and fauna. Soil health involves the management of physiochemical and biological capabilities to sustain all forms of life and their growth and development. Soil is one of Earth's most biologically diverse habitats, hosting many microorganisms. Soil biodiversity enhances significant ecosystem functions. Plant, soil, and extreme environments' microbiomes show exceptional qualities pertinent to managing global nutrient balances and ecosystem functions. These microbiomes derived from different niches enhanced plant growth and productivity through nutrient solubilization, nitrogen fixation, availability of nutrients, and tolerance against biotic and abiotic stresses. Soil microbes are bacteria, viruses, fungi, nematodes, and protozoa.**

They have an important soil function that has accomplished multiple useful tasks in the soil system, helping biological nitrogen fixation of different biological transformations that support the accumulation and utilization of nutrients, provide root and shoot growth processes, disease control, and promote soil quality in crop cultivation. This review has implications for the huge opportunities represented by soil microbes in sustainable agricultural growth by discussing their benefits in managing soil health and their interactions. Emerging new molecular techniques such as high throughput DNA sequencing and metagenomics are transforming our ability to study new information on specific genomes and genes from soil samples. Soil microbial diversity can be characterized and quantified using these new techniques, allowing for an examination of their implications for communities of plants, agricultural systems, agronomic activities, and soil richness.

Keywords—Microbiome, Rhizosphere, Mycorrhizal fungi, Symbiotic relationships, Metagenomics

I. Introduction

Soil can be recognized as the most biologically diverse habitat on Earth, hosting a wide array of microorganisms associated with important functions in ecosystem health and productivity. These include bacteria, fungi, protozoa, algae, and viruses. Microorganisms play a crucial role in creating and maintaining the biodiversity found in soil ecosystems. Soil biodiversity drives many of the massive ecosystem functions, such as nutrient turnover, decomposition of organic matter, and maintenance of soil structure. Even at a very small size, their influence on plants and the whole functioning of ecosystems is enormous because soil microbes are symbiotic with plants, improve nutrient availability in the soil, and protect plants from attack by pathogens. Referred to also as the "hidden majority" because of their great abundance and diversity, soil microbes harbor a vast reservoir of life's genetic diversity. Scores of species remain undiscovered and unknown. Their existence and activities are all directly linked to the health of the soil and extend to activities such as plant productivity and climate control. Knowledge and conservation of soil biodiversity are therefore most critical in sustaining agricultural productivity and ecological balance amidst various environmental challenges.

Soil microorganisms' involvement in ecosystem processes is still unexplored, especially if its extent is limited [1]. The rhizosphere is the region in the soil where microbial activity is high due to the influence of plant roots and is the habitat of an overwhelming number of microorganisms and invertebrates (nonskeletal organisms). Organisms that live in the rhizosphere microbial community can have substantial effects on the growth, nutrient cycling, and growth quality of the plants in agricultural ecosystems [2]. In crop productivity, microbes inhabiting the soil and plant systems can be used as bio-inoculants, which naturally increase the plant's nutritional needs by fixing, solubilizing, and chelating nutrients present in the soil and atmosphere. These beneficial soil and plant microbiomes can also control various abiotic stresses.

It has been evaluated that one gram of soil contains as many as 10^{10}-10^{11} microbes, bacteria 6000–50 000 bacterial species, up to 200 m fungal hyphae [1], and a wide range of Nematodes, mites, arthropods, earthworms [3].

Soil organisms interact in complex food webs, so changes in the diversity of one group can affect the numbers, variety, and roles of another. Therefore, understanding how changes in soil biodiversity and the simplification of soil communities impact ecosystem functioning is crucial [4].

The typical response of ecosystem multifunctionality depicts a strong positive linear relationship to indicators of soil biodiversity, suggesting that soil community composition is an essential factor in regulating ecosystem functioning [4].

In recent years multiple types of research have shown that human activities, such as agricultural intensification and land use change have decreased microbial abundance and the overall heterogeneity of soil organisms. Healthy soils are strongly linked to crop productivity. A diverse and balanced soil microbiome promotes plant growth by boosting nutrient availability, disease resistance, and soil quality. Microorganisms in the soil, particularly those in the zone impacted by plant roots, can form positive connections with crops, resulting in increased productivity and resistance to environmental challenges. As a result, maintaining a healthy soil microbiome is critical for maximizing agricultural output and ensuring food security.
Emerging new molecular techniques such as high throughput DNA sequencing and metagenomics are transforming our ability to study new information on specific genomes and genes from soil samples. These new tools, allow us to characterize and quantify the microbial diversity in soil samples, and to examine its impact on plant communities, cropping systems, agronomic practices, and soil fertility [5].

Microbes rapidly react to changes in the soil ecosystem and act as accurate indicators of particular functions within the soil environment [6].

In this review, we analyze the role of microbes that live beneath the ground indirectly and directly impact the efficiency, diversity, and productivity of plant communities. It will investigate the various functions of soil microorganisms, such as nutrient solubilization, nitrogen fixation, and biotic stress tolerance, pointing out their impact on plant health and development. The scope of this review encompasses the roles, interactions, and applications of soil microbiomes, emphasizing their ability to enhance environmentally friendly agricultural methods.

Plant microbial Interactions

The rhizosphere is a chemically complex zone with a varied microbiome that supports to control of the physicochemical properties of the soil, plant growth, development activities, and chemical signals exchanged between microbial communities and inhabiting plants [7].

Among the microbes inhabiting this ecological niche, bacteria play a critical role [6]. They are vital for several processes, including the breakdown of organic matter, nutrient recycling, and the development of symbiotic connections with both plants and animals. Protozoa and other microfaunal grazers regulate the amount of and turnover of rhizobacteria. The positive impact of protozoa on plant growth has been associated with nutrients that are released when protozoa consume bacterial biomass. This is referred to as a microbial loop [6].

This means they are more efficient in their environment compared to others. organic compounds liberated from roots promote bacterial growth, which can solubilize nutrients from the mineral soil layer and store them. Soil protozoa and nematodes consume bacteria and release nutrients, which will become available for plants [6].

Latest findings have further emphasized that, in non-cultivated ecosystems, plant community diversity and the genotypes of individual plants can influence the composition of their interacting communities both above ground and below ground. This also depicts why some plant species enhance the decomposition of their litter rather than that of other plant species or genotypes which gives them a “home-field advantage” [2].
Fungi play another important role in the rhizosphere. Most terrestrial plants form symbiotic relationships (mycorrhiza) with fungi in the soil [6]. In these interactions, the fungi provide the plant with access to water and soil nutrients due to complex hyphal structures, which originate from the root surface and spread deep into the soil, and the plant supplies carbohydrates for fungal growth and maintenance in return [6].

Soil microorganisms can synthesize significant plant hormones known as phytohormones like auxins**,** gibberellins**,** salicylic acid (SA)**,** abscisic acid (ABA)**,** and cytokinins within plant tissues. These hormones**,** secreted by rhizosphere microbes**,** are promising biotechnological targets for promoting plant resilience to abiotic stressors[8].

Plant Growth-Promoting Rhizobacteria (PGPR) can synthesize significant plant hormones known as phytohormones like auxins**,** gibberellins**,** salicylic acid (SA)**,** abscisic acid (ABA)**,** and cytokinins within plant tissues. These hormones**,** secreted by rhizosphere microbes**,** are promising biotechnological targets for promoting plant resilience to abiotic stressors [8]. Gibberellins support the germination and elongation in plants and regulate plant growth by degrading DELLA proteins. Cytokinins are significant in cell division and defense responses against parasitic pathogens. Microbial-mediated enhance the level of cytokinins in the plants are widely reported. Microorganisms also produce ACC (1-aminocy clopropane-1-carboxylate) deaminase that reduces ethylene levels in plants to mitigate the secondary effects of stress. phytohormone-producing microbial communities related to plant growth promotion are indicators in plant health management strategies [7].

Microbial adaptation to environmental conditions.

Microbes in soil can adapt to a diverse range of substrates, as well as physical, chemical, and biotic circumstances. These factors all contribute significantly to the structure of communities. A rich and varied environment is made open for microorganisms to establish themselves in by the diversity of substrates found in soil, including organic matter, minerals, and different types of nutrients. Because of their distinct adaptations, each organism can only use a limited number of substrates, establishing a highly specialized ecological niche.

Temperature, moisture content, and soil texture are among the physical factors that also affect the distribution and amount of soil organisms. Microbial growth and survival can also be impacted by chemical factors such as pH, salinity, and the presence of particular ions or substances. The dynamic balance within soil communities is

also influenced by biotic interactions like symbiosis, competition, and predation.

Certain organisms have developed the ability to survive on extremely specialized substrates, including lignin-rich plant matter or certain minerals, which allows them to play distinct roles in the cycling of nutrients and decomposition processes. These adaptations ensure their survival and improve their capacity to support ecosystem processes and improve the condition of the soil. Through their efficient breakdown of complex chemicals, these specialized organisms restore the soil with vital nutrients that promote plant development and maintain the ecological balance. It is essential to comprehend these complex interactions and responses to increase ecosystem resilience and soil biodiversity.

For example, different fungi prefer different compounds that grow best on sucrose, while others thrive on cellulose, lignin, or tannin–protein substrates. Environmental factors also affect organisms' presence. Oxygen levels, moisture, and pH can be selected for specific organisms, with different levels of these parameters influencing selection pressure [9].

Types of microbes

A. Bacteria

Bacteria are called bags of enzymes/fertilizer soluble bags [8] and are simply in structure. Bacteria (2-50 μm) can be identified as a major class of microbes that help to maintain soil productivity and health [10]. Most bacteria can be classified into bacteria shape, gram-positive or gram-negative bacteria, aerobic and anaerobic bacteria, and another way is bacterial growth and reproduction.

Nitrogen-fixing bacteria like Azaspirillum species related to the endophytic diazotrophic classes colonizing the surface and inside of roots, which is globally introduced as bio-nitric nitrogen fixation. Azospirillum specifically boosts root and root growth increases the rate of water and mineral intake per root, and manages the soil quality [8].

agricultural crop production bacteria play an essential part in providing soil nutrients, promoting plant growth, like plane hormone development, or controlling plant pathogens, boosting the soil composition, bioaccumulation, and bioleaching [8].In agricultural soils, there is a decline of nutrients by crop harvest, deficits by leaching, and evaporation removes significant amounts of nitrogen and other nutrients that support crop production [7].

However, bacterial communities in soil interacting with other plants and organisms play a vital role in fixing the biological nitrogen available for plant roots and liberating organic nitrogen by breaking it down into nitrogen-rich plant residues[8]. *Azotobacter, Azospirillum, Rhizobium, MesoRhizobium, SinoRhizobium* are identified for enhancing plant growth[8]. Soil bacteria help to weather soil minerals, promote soil formation, and produce polysaccharides to hold soil particles together and improve aggregate stability [11]. Also, Bacterial diversity is significant in carbon mineralization[3]. Bacteria that trigger the nodules at the roots of leguminous plants are commonly referred to as *"Rhizobia"* [8].

Cyanobacteria contribute to the nitrogen cycle in the soils of the forest ecosystem. In paddy cultivation, various N-fixing cyanobacteria fulfill the N requirement of the crop plants [7], Azolla Anabaena symbiosis has been assessed to contribute around 600kgNha−1, and *Peltigera aphthosa also* contributes to N-fixation using vanadium nitrogenase [7]. Some studies have been mainly observed for microbes belonging to the *Pseudomonales, Streptomycetaceae, and Micromonosporaceae*, which are an order and two families of bacteria, respectively, that can control plant pathogens. Some studies indicate that the plant genotype can impact the accumulation of microorganisms that help the plant defend itself against pathogen infection [12].

B. Fungi

Fungi are microscopic cells that generally grow as long threads or strands called hyphae that interact with soil particles, roots, and rocks, forming a filamentous body that boosts food exploration. Fungi are major in water dynamics, nutrient cycling, and disease control [13]. Fungus promotes recycling both N and phosphorus (P) to plants and most bacteria are early decomposers with the sugar fungus *(Zygomycetes)*. Still, most of the fungi support decomposing more resistant organic matter (recalcitrant) high in cellulose and lignin [13].

Many beneficial fungi help control diseases. Nematode-capturing fungi that infect harmful nematodes, and fungi that consume insects can serve as biological control agents. Fungi commonly found in agricultural or grassland soils include Ascomycetes (such as the soil genus *Saccharomycetes),* which are microscopic [13].

Rhizopus oryzae as a natural binding agent to improve soil stability in coastal environments. Unconfined compression tests on Miami Beach sand treated with *R. oryzae* demonstrate significant improvements in strength and durability, comparable to those observed with *Rhizopus oligosporus*. Notably, *R. oryzae* exhibits remarkable longevity in maintaining soil stability without additional water or nutrients, attributed to its extensive mycelial network [14].

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Mycorrhizal fungus is a mutualist fungus group, creating a symbiotic relationship with many plants that can provide resistance to disease and drought, and supply a range of limiting nutrients including N, P, Copper, iron, and zinc to the plant in exchange for carbon [1].

Mycorrhizal fungus enhances plant growth quality and major player in soil composition and entrusted with the translocation of nutrients, especially soil phosphorous, and improves nutrient and water uptake. These key play a major role in stressed environments, phosphorous-deficient soils, drought conditions, eroded zones, and acidic and reclaimed lands while the association with mycorrhizal fungi and rhizobia also affects the host plant by improving nitrogen and phosphorous [11].

The abundant and important groups of mycorrhizal fungi are the arbuscular mycorrhizal (AM) fungi, the

ecto-mycorrhizal (EM) fungi, and the ericoid mycorrhizal (ERM) fungi. Some studies reported that AM fungi enhance plant productivity in grassland.AM fungi enhance Phosphorous uptake is one of the mechanisms by which AM fungi can increase plant productivity. Studies have shown that AM fungi contribute to up to 90% of plant Phosphorous uptake which is especially significant for plant species with high P-requirement [1].

C. Algae

Algae are a very large and varied group of simple, usually autotrophic organisms that can perform photosynthesis and capture energy from sunlight. They are used as biofertilizers and soil stabilizers [8].

.Algae plays a crucial role in the initial stages of soil formation, particularly during the colonization of abiotic ground. They contribute to developing a primary layer abundant in organic carbon on the mineral substrate. Almost to the present, this role has often been attributed to lichens. However, recent studies highlight the significant influence of algae in these early processes. Autotrophic algae play a vital role in the soil by producing and accumulating organic matter, which increases the development of heterotrophic organisms. In the soil environment, they begin biochemical processes that release nitrogen and phosphorus. Potassium, calcium, magnesium, and other microelements are released from mineral compounds.

Algae promote soil formation in arid and semiarid regions as well as moderate climate zones. Algae, lichens, and lower plants are significant in forming the basic biological foundation in arid areas, where their roles in soil formation are better understood than in moderate climate zones. In arid environments, these organisms are often the primary pioneers, establishing life in severe conditions where higher plants struggle to survive [13].

The abundant growth of the algae in the first period is beneficial in the aeration of the upper layer of the submerged soil. There are some significant studies related to Nitrogen fixation by certain blue-green algae isolated from the soil of an Indian rice field [15].

By joining soil particles together to prevent and reduce soil erosion, algae promote enhanced water conservation in soils for longer periods. They also retain large amounts of oxygen in the soil through photosynthesis, which controls nitrate depletion. Additionally, algae assist in the leaching and drainage process, especially in up-cropped soils, and contribute to rock weathering and building the soil structure [8].

D. Protozoa

Protozoa are single-celled organisms that primarily consume bacteria, also ingest other protozoa, dissolved organic matter, and sometimes fungi. These microorganisms are several times larger than bacteria, with sizes ranging from 5 to 500 micrometers in diameter. Both protozoa and nematodes are aquatic and live and move through the water films and moisture-filled pores of soil aggregates. Their abundance in soil is essential for nutrient cycling and maintaining soil health. Protozoa play a crucial role in nutrient mineralization, making nutrients available for plants and other soil organisms and manage microbial/bacterial equilibrium in the soil [8].

Also, protozoa perform the role of biological control agents against organisms that cause harmful diseases in plants ratio of about 10:1 compared to the 3:1 to 10:1 ratio for bacteria. When protozoa eat bacteria, they release the excess nitrogen as ammonium (NH4+), which occurs near plant root systems. While bacteria and other organisms absorb most of this ammonium, some of it is also utilized by plants, supporting their growth and nutrient uptake [16].

E. Nematodes

Nematodes, or roundworms, are unsegmented worms with tapered ends typically 50 μm in diameter and 1/20 of an inch (1 mm) in length. They have a head, and a tail with a well-developed central nervous and fertility system with a complete digestive system, so they are referred to as the most primitive animal. They are considered the most primitive animals which are small enough to fit in most soil pores and soil aggregates [17].

Nematode community plays vital roles in soil and serve as biological pest control agents in managed systems and others control the natural ecosystem and soil nutrient cycling. Some consume plants and algae, others are grazers that depend on bacteria and fungi, and some depend on other nematodes (higher trophic levels). Different types of nematodes roles at several trophic levels of the soil food web. Nematodes are most live on the surface soil horizon. nematodes in mineralize, or liberate, nutrients in plant-available forms. When nematodes eat bacteria or fungi, ammonium (NH4 +) is released because bacteria and fungi contain much more N than the nematodes require [17].

F. Virus

Viruses play a crucial role in shaping the structure, function, and evolution of prokaryotic communities in soil. They promote bacterial genetic diversity and influence community structure and dynamics. Viruses can affect nutrient cycling by lysing bacterial cells, which release organic matter and nutrients back into the soil, enhancing soil fertility and health.

Soil viruses can potentially be used for biocontrol by infecting and controlling soil-borne plant pathogens, and reducing the reliance on chemical pesticides [18].

Role of Soil Microbiomes in Nutrient Cycling

Soil microbiomes like bacteria, fungi, and archaea, play a critical role in nutrient cycling within ecosystems. They convert and mobilize nutrients essential for plant growth and soil health, ensuring sustainable agricultural systems. Microbes increase nutrient availability through several processes, facilitating plant growth.

Molecular nitrogen is an unlimited resource consist with 78% of the atmospheric gases. Hence agricultural

productivity is typically reduced by the availability of N. Source of N chemically or biologically must be converted (N2-fixation) into a plant-available form (ammonia). Bacteria belonging to diverse genera, termed "*rhizobia*", fix N2 in mutualistic symbiosis with legume plants, while others (actinomycetes), belonging to the genus *Frankia*, forms N2-fixing nodules on the root of the so-called "actinorrhizal" plant species. Associative bacteria are capable of colonizing root surfaces. which can invade intercellular tissues within the plant. Other bacteria form diazotrophic rhizocenosis, like *Azospirillum*, which are free-living N2-fixing rhizobacteria but live more closely associated with plant roots than the rest of free-living bacteria. *Azospirillum* enhances N supply to the plant but acts mainly by increasing the ability of the root system for N uptake from the soil rather than as N2 fixing bacteria. The *rhizobia* legume symbiosis is the most important and most efficient N2-fixing system [23].

Phosphorus (P) availability is a major limiting factor for crop yield in many arable soils. Some microorganisms have the capacity to mobilize P from sources that are not easily available. Microbial activities result in an increased release of available P from minimally available soil P forms, either inorganic (solubilization) or organic (mineralization). Bacteria and fungi isolated from soil can hydrolyze organic P substrates, a process considered as mineralization of organic P which results in the liberation of orthophosphate to the soil solution. Soil microorganisms are crucial for the functioning of the soil P cycle. Diverse genera possess species able to solubilize phosphates, including bacteria, like *Bacillus, Enterobacter, Rhizobium, Bradyrhizobium, Panthoea, Erwinia*, and *Pseudomonas*, and fungi, like *Aspergillus*, *Trichoderma,* and *Penicillium*. The availability of orthophosphate makes the nutrient available for plant uptake. orthophosphate is made available by P mobilizing microorganisms, the nutrient can be absorbed and transported to the plant roots [23].

Microbial degradation of organic materials and availability of nutrients.

Organic matter is predominantly present in the top 20–30 cm of most soil profiles and consists primarily an array of organic macromolecules [19]. Microscopic organisms are the main agents of biochemical degradation and turnover of organic matter but soil fauna facilitates the breakdown of large particulate matter into finer fractions and affects the distribution of organic matter in soil. By fragmenting organic matter, which increases the surface area available for attack by microbial decomposers, soil fauna directly increases microbial populations and activity.

Decomposed organic matter stores nitrogen, phosphorus, and sulfur. There is a very small amount of inorganic nitrogen in soils and most of it is derived from organic forms. Factors such as temperature, moisture content, and microbial diversity all drive the decomposition of soil organic matter. The breakdown of organic material is, to a large extent, a catalytic/enzymatic process facilitated by extracellular hydrolytic enzymes produced by soil microorganisms. The important soil enzymes are amylase, arylsulfatase, cellulase, chitinase, dehydrogenase, phosphatase, and urease which are released from plants, animals, organic compounds, and microorganisms and soils and are involved in the biochemical processes during organic matter decomposition [19].

Soil fauna, involving nematodes, protozoa, and saprotrophic fungi, is concerned with the decomposition of organic matter and plant and animal residues. Such processes liberate nutrients that were earlier bound to organic compounds. Nutrient cycling will also be enhanced by the activity of soil microorganisms, which includes bacteria and fungi, through very fundamental processes like nitrogen fixation, nitrification, and denitrification. Through processes like nitrogen fixation, atmospheric nitrogen is converted into plant-available forms; in nitrification, ammonium is converted into nitrate; and in denitrification, excess nitrate is reduced back to nitrogen gas, thus preventing nutrient accumulation and the associated environmental problems. Simply put, these microbial activities, in the process of mineralization of nutrients, make the same available for uptake by plants and consequently for their growth. Since these get absorbed by the plants and finally decompose, the cycle of organic matter and nutrient availability ensures the fertility of the soil and the sustainability of the ecosystem [3]. The interactions between soil microflora and fauna have been mostly studied in earthworms. However, other groups of invertebrates that live in soil undoubtedly play a major role in the development and cycling of organic material, in particular mesoarthropods such as mites and Collembola. The range of which these various groups of soil fauna regulate decomposition may depend on the ecosystem. Microarthropods that depend on fungi, especially Collembola, can play a key role in no-tillage agroecosystems but are less important in traditional tillage systems [19]. Although limited research has been conducted, it seems probable that, like earthworms, microarthropods can play significant roles in influencing the activities of microorganisms in organic matter decomposition in soil.

The initial organic matter in soil comes from algal biomass and has an important effect on soil development among organic compounds like carbohydrate derivatives, nitrogen, sulfur, and oxygen compounds such as pyrane, and furane derivatives [13]. Rapid decomposition and humification of algal biomasses accumulate organic matter in soil which becomes a source of nutrients for early and later succession species with higher habitat requirements [13].

Adding organic matter into soils can alter the amount of nitrogen (and other nutrients) available to plants, and those having a high C/N ratio will cause some nitrogen deficiency in the crops/plants, at least in the short term [20].

Soil Microbiomes and Sustainable Agriculture

Soil is a fundamental component of the ecosystem, supporting the foundation for terrestrial life forms by providing essential nutrients, water, and a medium for growth. It supports a diverse range of organisms, including plants, fungi, animals, and bacteria, all of which contribute to the ecological balance. Soil protection becomes the

highest priority due to its significance for biodiversity, agricultural productivity, and climate change stabilization.

A comprehensive understanding of soil enzyme activity is critical for keeping soil healthy. Soil enzymes, which are stimulated by microbes and plant roots, aid in the breakdown of organic matter, nitrogen cycling, and other biochemical activities that maintain soil fertility and structure. We may gain knowledge about the general health and function of soil ecosystems by investigating soil enzyme activities. A greater understanding of the role of these enzymes in soil health will allow for a more accurate assessment of soil quality and resilience.

Microorganisms are especially sensitive to environmental stress because of their high surface-to-volume ratio [20]. These features enable them to rapidly associate with their surroundings, responding to variations in moisture, temperature, and nutrition supply. As major decomposers, microorganisms break down organic matter and release nutrients back into the soil, making them essential indicators of soil health. Their quick response to environmental changes makes them useful tools for monitoring soil health and implementing sustainable soil management methods. Understanding these dynamic processes is critical to developing methods to maintain and improve soil resources, so assuring the survival of life on Earth.

Soil that is healthy enhances the health of plants and animals, hence facilitating ecosystem endeavors. The health of arid soil is impacted by disturbances and perturbations which can impact the physical chemical and biological components of the soil in various ways depending on the level of disturbance or change. Soil erosion, desertification,sodification, salinization, and other soil contaminants have an impact on the soil microbial community [11].

Minimum tillage over conventional tillage facilitates much better soil and moisture conservation options to promote soil quality as it improves the population of aerobic and facultative aerobic microorganisms significantly as compared to deeply plowed soils. Content of organic C, organic N, potentially mineralizable N, water, phosphatase, and dehydrogenase enzymes were also significant in zero-till soils. Soil fertility and plant growth improved by microbial inoculants. Vermicompost combined with microbial inoculants such as Glomus sp., Chlorella sp., Bacillus megaterium, B. subtilis, Panibacillus azotofixans, and Pantoea agglomerans with different combinations enhances the stability of aggregates and the amount of organic carbon in clay loam [7].

As highlighted in several studies, organically managed soil systems depict significant advantages over conventional systems. Some investigations realized that the composition and diversity of microbial communities in soil using next-generation sequencing techniques targeted on the 16S rRNA gene which provide key insights into the phylogenetic richness, diversity, and heterogeneity of soil microbiota, demonstrating that organic management practices enhance microbial diversity and richness compared to conventional methods.[21].

The investigation of the favorable effects of organic amendments on the health of the soil revealed that regular application of organic substrates such as charcoal, alfalfa hay, and glucose improved soil microbiota composition, resulting in increased crop yield in Eruca sativa (arugula). This emphasized the capacity of organic matter to boost soil fertility sustainably by improving microbial populations [21].

An investigation on the impact of using pelletized spent mushroom substrate, an organic substance, in combination with mineral fertilizers on soil health and barley performance. The findings indicate that organic additions promote plant growth and development while also increasing the diversity of soil microorganisms, implying that organic inputs benefit both soil health and agricultural productivity [21].

Overall, this research underlines the benefits of organic management approaches for soil health, microbial diversity, and crop output. Farmers can accomplish sustainable soil fertility management and promote more productive agricultural systems by using various organic amendments in place in conventional approaches.

Technological Advances in Soil Microbiome Research

Soil microbial communities are essential to maintaining significant soil processes associated with the breaking down of litter, nutrient cycling, and plant productivity and they are crucial for human well-being. Recent advancements in technology have exponentially expanded our knowledge concerning the global ecological distributions of microbial communities across period of time and have provided valuable insights into their contribution to ecosystem functions [22].

The direct extraction and study of communities of microbial DNA by PCR amplicon surveys and metagenomics has changed the field of environmental microbiology and microbial ecology. Metagenomic analysis of nucleic acids allows scientists to direct access to the genomes of the vast number of microorganisms that cannot be cultured in the lab. Microbiologists have discovered numerous unique phyla, classes, genera, and genes from microbes in the initial decade and a half of the twenty-first century, exceeding insights made since Antonie van Leeuwenhoek first examined microorganisms [23].

Soils' unparalleled diversity offers ongoing research into a wide range of industrial, agricultural, and environmental activities. Exploring soil microbial communities with these advanced tools holds great potential for answering the many outstanding questions like who, what, where, when, and why. Which microorganisms are associated with which soil habitats? How do microbial populations change with changing edaphic conditions? How do microbial communities interact with each other, either cooperatively or competitively? What is the full extent of soil microbial diversity, both functionally and in evolutionary lineage? What are the dynamic features of microbial communities in space and time? How susceptible are microbial populations to climate change and how do they adapt? How does horizontal gene transfer affect the stability of microbial communities? Do highly diverse microbial communities enhance soil resilience and resistance to disturbances? [23].

The scientific community needs both detailed studies and broad-scale surveys to better explain the soil microbial communities, understand microbial population, analyze the microbial and environmental interrelationships, detect and interpret microbial diversity, study functions that can be exploited for industry and agriculture, and clarify microbial adaptation and evolution within the context of soil services. Microbial ecologists have been based on the assessment of limited datasets, akin to microbial satellite imagery over a prolonged time [23].

Microbe-mediated plant salt resilience, in particular on the functional and molecular mechanisms underlying root-microbe interaction. When introducing such microbes as single strains to soils, they are often Inefficient in enhancing plant development and stress tolerance, largely due to Contest with native microbial populations in soil and limited colonization capability. Rapid progress in rhizosphere microbiome studies has emphasized the belief that plants may benefit more from association with Interconnected, diverse microbial ecosystems (microbiome) than from individual members in a community [24].

Understanding how a microbiome assembles in the continuous compartments (endosphere, rhizoplane, and rhizosphere) will support in predicting a subset of Basic or minimal microbial communities and facilitate the synthetic rebuilding of microbial networks and their functional compatibility and synergistic outcome effects. These advancements will open a new path for capitalizing on the cultivable microbiome to strengthen plant salt tolerance and optimize agricultural methods and productivity [24].

Some examples where the application of a multi-omics approach emphasized how selected plant exudates produced under natural or adverse situations can affect root colonization by particular microbes. Combined metabolomics and Targeted metagenomic sequencing on two maize genotypes (wild type and a benzoxazinoids precursor mutant) revealed how the defense-related benzoxazinoids metabolites structure the bacterial and fungal community of the maize rhizosphere. Also exploited the combination of shotgun metagenomics and metabolomics on an array of Arabidopsis mutants to demonstrate that root exudation of coumarins can shape the rhizosphere microbiome [25].

Similarly, metabolomics and metagenomics reveal the effect that root-exuded triterpenes have on the microbiota composition of the root. The biochemical drivers of the “legacy effect” by combining metabolite profiling of the root exudates of infected plants with metagenomic analysis of the rhizospheres of these plants. Furthermore, an elegant combination of external metabolomics, metagenomics, and comparative genomics demonstrated how time-dependent exudation of root metabolites during different plant developmental stages assembled specific microbial communities and enriched them for specific microbial functions. In the following phase, need to relate how secreted plant chemicals can affect microbial metabolism and uncover how plant secretions can specify which root niches can be occupied by beneficial microorganisms while inhibiting dangerous infections [25].

To create synthetic microbial populations that have consistent positive influences on vegetation in the field, it is critical to understand whether a single strain's peculiar trait exists at the community level and in various circumstances (which vary environmental conditions, hosts, other microorganisms, etc.). It is important to recognize that particular isolates or synthetic communities that show favorable effects via in vitro testing and under controlled settings might act in distinct ways in the field. We should also recognize that as the synthetic community becomes more complex, the practicality of producing microbial inoculants on a large industrial scale decreases. This should be considered in future plant-microbiome investigations with a translational intent since many methodologies and tools need to be combined to design small and effective synthetic communities that can support the host plants with consistent and predictable outcomes [25].

Future advancement in microbial spatial distribution linked with the use of synthetic biology, Novel techniques for microbial cultivation, and various omics technologies (e.g., metatranscriptomics, metaproteomics, and metabolomics). may assist us in using the microbiome of the soil to improve crop yield and overall wellness in an evolving world. We are still far from understanding the roles and processes being conducted by every single microbial species and their impact on terrestrial functions, yet synthetic biology approaches have been suggested to improve ecosystem restoration, rhizosphere-driven crop yield, and pest management [22].

Challenges

The distribution of soil biodiversity is poorly understood when compared to aboveground ecosystems, and this presents serious difficulties in terms of research and conservation. Knowledge gaps are particularly acute in the Global South, which is less represented in the scientific literature. New efforts to form global databases of soil taxa have led some researchers to formulate maps of spatial distributions of soil taxa such as nematodes, bacteria, or fungi-, however, these databases, also indicate that there are major knowledge deficits in the fields of biogeography, biomass and functional variability. Most worrying, just 37% of those areas in which above-ground biodiversity is high, also seem to be low, so there is a mismanagement of conservation priorities [27]. Furthermore, in recent years due to the lack of taxonomic specialists active interest in invertebrates has declined moderately which makes many conservation and identification of species far more complex. The majority of soil organisms are considered to be small in size and are thought to have a greater proportion of unclassified organisms than their larger counterparts, which poses further challenges for conservation. Adequate awareness of the genetic diversity of notably known within soil biota is imperative as it has implications on the degree of ecological resistance and potential for pharmaceuticals, and the absence of knowledge in this regard affects our preparedness for climate change. While soil organisms are essential to nutrient recycling, it is clear that this is a fact that is often ignored [26].

II. Conclusion

Soil microbial communities are referred to as hidden wonders that play significant roles in ecosystem well-being. They have been known as potential solutions to one of the major problems issues in crop production and land degradation.

The soil microbial community is more varied than any other group of organisms. The functions of these communities are diverse from nutrient cycling and organic matter decomposition.

The soil microbes are bacteria, fungi, viruses, nematodes, and protozoa. They produce plant growth hormones and metabolites that influence plant growth and development. Soil microbial communities are critical to decomposing organic matter and recycling soil nutrients. They provide nutrients to crops and promote soil health and crop outputs. Soil microbes play a substantial part in the tolerance to plant diseases. Regarding the environmental damage associated with the application of chemical fertilization. The use of microbes in agricultural sustainability and land management helps remove toxic substances that are major causes of land degradation, and increasing soil fertility. Advantageous microbial communities establish in the rhizosphere, live in the internal tissues of plants, and form an important part of soil ecosystems. Plant-microbe interactions open opportunities to understand the relationships among soil microbiomes, plants, and other living organisms.

These interactions reveal the role of soil and microbiomes, in enhancing plant growth and development, supporting soil fertility, and supporting the overall ecosystem stability.

Advance new molecular techniques such as high throughput DNA sequencing and metagenomics are transforming our ability to study new information on specific genomes and genes from soil samples. These new tools, allow us to characterize and quantify the microbial diversity in soil samples, and to examine its impact on plant communities, cropping systems, agronomic practices, and soil fertility

A review prioritizing the enhancing plant-soil microbe nutritional interactions is essential for more sustainable agricultural and crop production systems.

Ecological investigations have upgraded our understanding of microbial diversity and increased our knowledge of the functional roles of microbial communities in the ecosystem.

References

[1] Van Der Heiden MG, Bardgett RD, Van Straalen NM. The unseen majority: soil microbes as drivers of plant diversity and productivity in terrestrial ecosystems. Ecology letters. 2008 Mar;11(3):296-310.

[2] Philippot L, Raaijmakers JM, Lemanceau P, Van Der Putten WH. Going back to the roots: the microbial ecology of the rhizosphere. Nature reviews microbiology. 2013 Nov;11(11):789-99.

[3] Bender SF, Wagg C, van der Heijden MG. An underground revolution: biodiversity and soil ecological engineering for agricultural sustainability. Trends in ecology & evolution. 2016 Jun 1;31(6):440-52.

[4] Wagg C, Bender SF, Widmer F, Van Der Heijden MG. Soil biodiversity and soil community composition determine ecosystem multifunctionality. Proceedings of the National Academy of Sciences. 2014 Apr 8;111(14):5266-70

[5] Bhatia CR. Role of microbial diversity for soil, health and plant nutrition. InMolecular mechanisms of plant and microbe coexistence 2008 Jul 10 (pp. 53-74). Berlin, Heidelberg: Springer Berlin Heidelberg.

[6] Dion P. Molecular mechanisms of plant and microbe coexistence. Nautiyal CS, editor. Berlin: Springer; 2008.

[7] Sahu PK, Singh DP, Prabha R, Meena KK, Abhilash PC. Connecting microbial capabilities with the soil and plant health: Options for agricultural sustainability. Ecological Indicators. 2019 Oct 1;105:601-12.

[8] Shah KK, Tripathi S, Tiwari I, Shrestha J, Modi B, Paudel N, Das BD. Role of soil microbes in sustainable crop production and soil health: A review. Agricultural Science and Technology. 2021 Sep 18;13(2):109-18

[9] Schimel JP, Schaeffer SM. Microbial control over carbon cycling in soil. Frontiers in microbiology. 2012 Sep 26;3:348.

[10] Hoorman JJ. The role of soil bacteria. Ohio State University Extension, Columbus. 2011:1-4.

[11] Kennedy AC, Stubbs L. Soil microbial communities as indicators of soil health. Annals of arid zone. 2006;45(3 & 4).

[12] Berendsen RL, Pieterse CM, Bakker PA. The rhizosphere microbiome and plant health. Trends in plant science. 2012 Aug 1;17(8):478-86

[13] Rahmonov O, Cabala J, Bednarek R, Rozek D, Florkiewicz A. Role of soil algae on the initial stages of soil formation in sandy polluted areas. Ecological Chemistry and Engineering S. 2015 Oct 1;22(4):675-90.

[14] Jerez Lazo C, Lee N, Tripathi P, Joykutty L, Jayachandran K, Lee SJ. A fungus-based soil improvement using Rhizopus oryzae inoculum. International Journal of Geo-Engineering. 2024 Jul 27;15(1):18.

[15] De PK. The role of blue-green algae in nitrogen fixation in rice-fields. Proceedings of the Royal Society of London. Series B-Biological Sciences. 1939 Mar 10;127(846):121-39.Hoorman JJ. Role of Soil Fungus: Update and Revision. Ohio State Univ. Ext. 2009.

[16] Hoorman JJ. The role of soil protozoa and nematodes. Fact sheet: agriculture and natural resources. The Ohio State University Extension, Colombus, OH. 2011:1-5

[17] Hoorman JJ. The role of soil protozoa and nematodes. Fact sheet: agriculture and natural resources. The Ohio State University Extension, Colombus, OH. 2011:1-5.

[18] Roy K, Ghosh D, DeBruyn JM, Dasgupta T, Wommack KE, Liang X, Wagner RE, Radosevich M. Temporal dynamics of soil virus and bacterial populations in agricultural and early plant successional soils. Frontiers in microbiology. 2020 Jul 7;11:1494.

[19] Condron L, Stark C, O'Callaghan M, Clinton P, Huang Z. The role of microbial communities in the formation and decomposition of soil organic matter. Soil microbiology and sustainable crop production. 2010:81-118

[20] Sahu N, Vasu D, Sahu A, Lal N, Singh SK. Strength of microbes in nutrient cycling: a key to soil health. Agriculturally Important Microbes for Sustainable Agriculture: Volume I: Plant-soil-microbe nexus. 2017:69-86.

[21] Kaul S, Choudhary M, Gupta S, Dhar MK. Engineering host microbiome for crop improvement and sustainable agriculture. Frontiers in Microbiology. 2021 May 28;12:635917.

[22] Chu H, Gao GF, Ma Y, Fan K, Delgado-Baquerizo M. Soil microbial biogeography in a changing world: recent advances and future perspectives. MSystems. 2020 Apr 28;5(2):10-128.

[23] Nesme J, Achouak W, Agathos SN, Bailey M, Baldrian P, Brunel D, Frostegård Å, Heulin T, Jansson JK, Jurkevitch E, Kruus KL. Back to the future of soil metagenomics. Frontiers in microbiology. 2016 Feb 10;7:73.

[24] Qin Yuan QY, Druzhinina IS, Pan XueYu PX, Yuan ZhiLin YZ. Microbially mediated plant salt tolerance and microbiome-based solutions for saline agriculture.

[25] Pascale A, Proietti S, Pantelides IS, Stringlis IA. Modulation of the root microbiome by plant molecules: the basis for targeted disease suppression and plant growth promotion. Frontiers in plant science. 2020 Jan 24;10:1741.

[26] Bach EM, Ramirez KS, Fraser TD, Wall DH. Soil biodiversity integrates solutions for a sustainable future. Sustainability. 2020 Mar 27;12(7):2662.

Effect of film thickness on characteristic properties of thermally evaporated copper oxide thin films

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ABSTRACT

Copper oxide (CuO) is regarded as one of the most promising materials for heterojunction solar cells. Due to its bandgap (~1.2 eV), CuO thin films have been used as the absorber material for the development of photonic devices. In this study, CuO thin films were deposited on the cleaned FTO glass substrates by varying the deposition duration in order to vary layer thicknesses using the thermal evaporation technique (PVD). The chamber pressure was maintained at 1.5 ×10 -5 Torr. Morphological and optical properties of the synthesized films were studied as a function of the film thickness. Scanning electron microscopy and UV–Vis spectroscopy were used to explore the morphology and optical properties of the films, respectively. Field emission scanning electron microscopy (FESEM) analysis revealed formation of nanoparticles with sizes in between 77.78 nm to 102.94 nm. Morphological studies have revealed that the uniformity of the film surface, and the average Nano particle diameter were found to increase with sample thickness increase. The bandgap was estimated from optical absorption measurements. The calculated bandgap value of copper oxide thin films increases from 1.78 eV to 2.78 eV when film thickness decreases. The lowest bandgap value was reported for the sample thickness at 50 nm. Moreover, the optical properties such as the bandgap energy of CuO were found to be influenced by the sample thickness. The study uncover method.

Keywords— Copper oxide, Film thickness, SEM, Thermal evaporation

INTRODUCTION

Copper Oxide (CuO) Nanoparticles have attracted significant research attention owing to their unique properties but also to their application level in different fields including catalysis aspects, energy storage, or environment remediation. These CuO nano-particles, having a monoclinic structure and narrow bandgap of about 1.2 eV are excellent in enhancing thermal conductivity, exhibiting strong antimicrobial activity, and having multiple catalytic capabilities than their bulk forms. On the other hand, Copper Oxide Nano Particles can be easily synthesized via thermal evaporation which ensures a straightforward production pathway to control size and diffusion.

In the thermal evaporation technique, we have taken rods of copper and vaporized it in an atmosphere richer in oxygen to yield CuO nanoparticles. This method allows for precise control over the nanoparticle properties (eg, size and shape) that are adjusted to optimize the working of the materials for their desired application. Also, the easy process followed in thermal evaporation makes it amenable to large-scale production with the least environmental degradation.

The characterization of synthesized CuO NPs through thermal evaporation is necessary for the comprehension of their structural and functional properties. Methods like X-ray diffraction (XRD), scanning electron microscopy (SEM), and thermo gravimetric analysis (TGA) are able to give the information about crystallinity, morphology, and thermal stability of these nanoparticles.

As a result of the synthesis method and the great merits of nanostructure materials, CuO nanoparticles show impressive properties and could be prospective candidates for developing next-generation technologies in the field of energy conversion, catalysis & beyond. This brief review is meant to pave the way for investigating CuO nanoparticles deposited by thermal evaporation in a more elaborate manner and to find out its potential applications.

METHODOLOGY

Preparation of CuO Nanoparticles

Firstly, FTO substrates were cut into 1.0 cm × 2.0 cm pieces and thoroughly cleaned with detergent. Then, they were washed with DI water and dried. Then, the glass plates were cleaned by immersing them in acetone, methanol, and isopropanol order just below their respective boiling points. Chemically cleaned substrates were then washed with DI water and dried with Nitrogen before being stored in a desiccator. The substrates were plasma-cleaned for 5 minutes to obtain a better hydrophilic surface. After that, to fabricate CuO films were deposited by the thermal evaporation technique by varying the deposition duration to have different layers of thickness from the Edwards vacuum coating unit using an aluminum-coated heating crucible onto a fluorine-doped tin oxide(FTO) glass substrate. CuO rods were used as the source material and the films were deposited at the chamber pressure maintained at ~ 1.5 ×10 -5 Torr using a rotary and diffusion pump system.

RESULTS

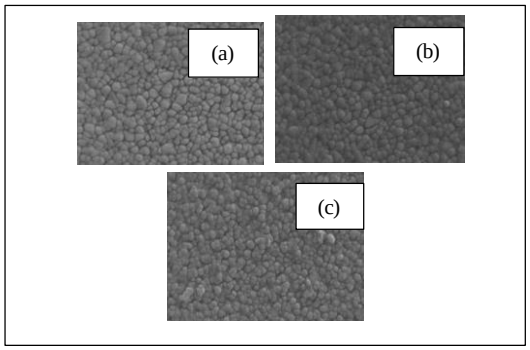

Figure 1: SEM image of termal evoparated CuO thin films prepared at film thicknesses a. 3 nm, b. 15 nm and c. 50 nm

Figure 1 shows the surface morphology of CuO thin films prepared at different layer thicknesses. The films deposited at 3nm appear to be relatively non-uniform and exhibit a surface with a porous nature. An increase in film thickness results in the film surface being observed to be uniform with a more compact structure. It is observed from Fig. b, c that the film surface is smooth, uniform, and well-covered the surface with nanoparticles. It was found that the value of the energy gap decreases with
increasing film thickness. The decrease in the value of the bandgap is understood in terms of the increasing particle size of the film. The optical properties and the optical bandgap were discovered using UV-visible spectrum analysis. The film deposited at 3nm and 15nm has the highest bandgap and is equal to the values 2.78eV and 2.51eV. 50nm film has the lowest bandgap and is equal to 1.87 eV. An optimum bandgap of 1.87 eV was observed for the thickness of the film in 50nm.

Thickness of the sample (nm)	Bandgap value (eV)	Average diameter of the nano particles (nm)
5	2.78	77.57
15	2.51	94.33
50	1.87	102.94

CONCLUSIONS

According to the optical absorption measurements indicate that the deposited film has a direct band gap value 1.87 eV to 2.78 eV for film thicknesses. Therefore, out of the investigated thicknesses, thickness at 50 nm enhanced the thermal evoparated CuO absorber layer properties.

REFERENCES

[1] J.A. Andrade-Arvizu, M.C. Piedrahita, O. Vigil-Galan, J. Mater. Sci. Mater. Electron. 26, 4541 (2015)

[2] Rabih L, Ali G G and Younus M H 2019 Evaluation of optical and electrical properties of TiO2 thin films doped Cu ions AIP Conf. Proc. 2201.

[3] I. S. Jacobs and C. P. Bean, “Fine particles, thin films and exchange anisotropy,” in Magnetism, vol. III, G. T. Rado and H. Suhl, Eds. New York: Academic, 1963, pp. 271–350.

[4] M. Young, The Technical Writer’s Handbook. Mill Valley, CA: University Science, 1989.

An Assessment of Carbon Sequestration and Biodiversity using the Shannon-Weiner Index of Trees for Sustainable Urban Campus Management: A Case Study at Sri Lanka Technology Campus

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***Abstract*— This study evaluates the carbon sequestration potential of tree species within the Sri Lanka Technology Campus (SLTC) to identify high-performing species and support the university's sustainability objectives. Carbon sequestration is vital for climate change mitigation, especially in semi-urban environments. The study involved a comprehensive inventory of 429 trees across 49 species. Measurements included Diameter at Breast Height (DBH), height, and biomass, followed by aboveground and belowground biomass calculations, dry weight, and carbon content. The Shannon-Weiner Index was employed to estimate biodiversity. The findings revealed that *Alstonia macrophylla* (Devil Tree), *Mangifera indica* (Mango), and *Azadirachta indica* (Neem) are the dominant species. However, *Kigelia africana* and *Acacia lebbeck* emerged as the most efficient species regarding carbon sequestration potential. The campus trees collectively sequestered approximately 442.9 tons of carbon. The presence of exotic species, such as *Alstonia macrophylla*, suggests a decline in native biodiversity, indicating the need for restoration. This research provides a framework for enhancing carbon sequestration through strategic species selection, supporting SLTC's role in climate change mitigation, and contributing to Sri Lanka's broader environmental goals. These findings also highlight the importance of regular tree monitoring and biodiversity promotion to maximize long-term carbon sequestration benefits.**

***Keywords*— Carbon sequestration, Shannon-Weiner Index, Tree biodiversity, Climate change mitigation, Exotic species**

I. INTRODUCTION

Climate change has become a pressing global issue, primarily driven by increasing atmospheric carbon dioxide (CO_2) concentrations resulting from human activities such as deforestation and fossil fuel combustion. Additionally, the Paris Agreement set long-term temperature objectives, aiming to limit the global average temperature increase to well below 2°C, while also trying to restrict it to 1.5°C [1]. Under the direction of international initiatives, numerous countries have been working together to lower their greenhouse gas (GHG) emissions through their intended nationally determined contributions (INDCs) [1].

Universities are crucial to societies globally, serving as hubs for lifelong learning opportunities [1]. Due to their numerous facilities and large populations that demand significant energy, university campuses can be regarded as small-scale models of entire cities[1]. Higher Education Institutions significantly account for greenhouse gas emissions through energy consumption in classrooms and hostels and indirectly contribute through activities such as transportation, fuel use, and waste on campuses[2]. And, many HEIs worldwide have adopted initiatives such as the "carbon-neutral university," aiming to transform into low-emission or carbon-neutral institutions[3].

One of the most effective strategies to mitigate these rising CO_2 levels is through carbon sequestration, the process by which trees and other vegetation capture and store atmospheric carbon in biomass and soils. Forests, in particular, play a critical role in sequestering carbon, with different tree species demonstrating varying levels of carbon absorption depending on their size, biomass, and growth rate [4]. Carbon stock assessments on university campuses can provide significant insights and implications that reach beyond the educational realm [1]. As influential knowledge hubs within urban environments, universities have a pivotal role in fostering and scaling up sustainability practices [1].

Trees and green spaces are essential for air purification, stormwater management, and carbon sequestration, all of which are vital for conserving biodiversity in urban settings and mitigating UHI impacts[5]. These benefits lead to several positive outcomes, including lower energy consumption in buildings, reduced ground-level ozone formation, improved outdoor thermal comfort, decreased heat-related stress events, and enhanced outdoor experiences during sunny and warm weather[5].

Sri Lanka, with its rich biodiversity and favourable climatic conditions, presents significant opportunities for enhancing carbon sequestration through afforestation and reforestation programs. As part of this initiative, the Sri Lanka Technology Campushas undertaken a project to assess the carbon sequestration potential of tree species within its campus. The study aims to contribute to the university's sustainability goals by identifying species with high sequestration potential and exploring strategies to enhance the campus's role as a carbon sink.

This project builds on these findings by conducting a detailed inventory of tree species within the SLTC Research University campus and estimating their carbon sequestration potential. In contrast to destructive methods, which involve felling and directly measuring tree biomass, this study utilized a non-destructive approach based on allometric equations to estimate carbon sequestration. The non-destructive method allows for accurate estimation of carbon storage without harming the trees, making it a more sustainable and practical approach for long-term ecological studies.

II. MATERIAL AND METHODS

A. Study Area Selection

Sri Lanka Technology Campus is established in the western province of Sri Lanka. It is in a semi-urban environment spanning an area of 46.3 acres. The extent covers diverse tree species to enhance climate change mitigation opportunities through the carbon sequestration potential.

Fig 1.Map of the study area. Mark Indicates in SLTC Research University

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B. Tree Inventory and Species Selection

A comprehensive tree inventory was conducted, identifying a total of 529 trees within the selected area. Out of these, 429 trees were selected for detailed measurements, while 100 trees were excluded due to poor health, insufficient size, or inaccessibility. The selected trees represented a wide range of species, including high carbon-sequestering species such as *Azadirachta indica* (Neem), *Mangifera indica* (Mango), and *Alstonia macrophylla* (Devil Tree).

Fig 03: A burnt tree

Fig 04: A deforested area

Fig 06: A dead tree

Fig 04: A tree with damaged bark

C. Tree Measurements

The following measurements were taken for each selected tree:

Diameter at Breast Height (DBH): The DBH of each tree was measured at 1.3 meters above ground level using a measuring tape.

Tree Height: The height of the trees was measured using an inclinometer.

Tree Volume Calculation: The tree volume was estimated based on the DBH and height measurements based on following formula.

$$V=\pi(d/2)^2h$$

where *d* is the DBH, and *h* is the height of the tree.

D. Biomass Estimation

The total biomass of the trees was estimated in two stages:

Aboveground Biomass (AGB): This was calculated using species-specific wood density values sourced from literature (Sharma et al., 2020). The formula used for AGB was:

$$AGB=\text{Tree Volume} \times \text{Wood Density}$$

Belowground Biomass (BGB): BGB was estimated using a Root-to-Shoot Ratio (R) of 0.26, based on the following equation.

$$BGB=AGB\times 0.26$$

Total Biomass: The total biomass was calculated by summing AGB and BGB:

$$\text{Total Biomass}=AGB+BGB$$

E. Biomass correction

The average tree, considering all species, consists of 72.5% dry matter and 27.5% moisture (Bada et al.,2018). Hence, to calculate the dry weight of the tree, the total green weight was multiplied by 72.5% [6].

. The dry weight of trees was calculated based on the following equation.

Dry weight(kg) = Total biomass x 0.725

F. Carbon Content Estimation

To estimate the carbon content, the biomass was multiplied by a carbon fraction, typically 0.5 for woody biomass. The formula used was.
Carbon Content=Total Biomass×0.5

G. CO_2 Sequestration Calculation

The total CO_2 sequestration for each tree species was estimated by converting the carbon content into its CO_2 equivalent. The conversion factor 44/12 was used to convert the carbon content into CO_2:

CO_2 Sequestration=Carbon Content×12/44

H. Data Analysis

Data were entered and analyzed using Excel software. Carbon sequestration rates were calculated and compared across different species to identify the most effective carbon-sequestering species on campus.

I. Estimation of biodiversity

Tree biodiversity was estimated based on the Shannon-Weiner Index as the following equation.

$$\text{Shannon Index (H)} = -\sum_{i=1}^{s} p_i \ln p_i$$

Where;
p_i is the proportion of individuals of species iii relative to the total number of individuals.
S is the total number of species.

III. Result and Discussion

429 trees belonging to 48 species were inventoried. *Alstonia macrophylla (20%), Macaranga peltate (16.28%) and Mangifera indica (12.09%)* were the dominant tree. species in the study area (Fig 5). 19 species out of the total were exotic while the majority (30 species) were native species to Sri Lanka.

Among exotic species, *Alstonia macrophylla (20%)* was the most abundant species while *Macaranga peltate (16.28%)* emerged as the most dominant native species. An abundance of exotic species may suggest a decline in native biodiversity, as these non-native species can outcompete native flora for resources, leading to changes in ecosystem structure. In addition, three endemic tree species, *Artocarpus nobilis*, *Garcinia quaesita*, and *Dipterocarpus zeylanicus*, were found within the study area, indicating high biodiversity.

Highly abundant native tree species such as *Mangifera indica* and *Artocarpus heterophyllus* provide habitats for various species, promoting ecological balance. Biodiversity supports pollinators, birds, and other wildlife, which can enhance the health of the surrounding environment.

Inventoried trees belonged to 27 families in this tree inventory. Among them, the Fabaceae family is the most widespread, with a significant 6 species, representing approximately 14.29% of the total species. *Delonix regia*, *Pterocarpus indicus, Bauhinia forticata, Pterocarpus santalinus, Gliricidia sepium, and Acacia lebbeck*, serve as examples of the diversity of the Fabaceae family Trees. Additionally, these trees demonstrate resilience in adverse environments, such as nutrient-poor soil, due to the effective nitrogen-fixation abilities of their associated Rhizobacteria [7].

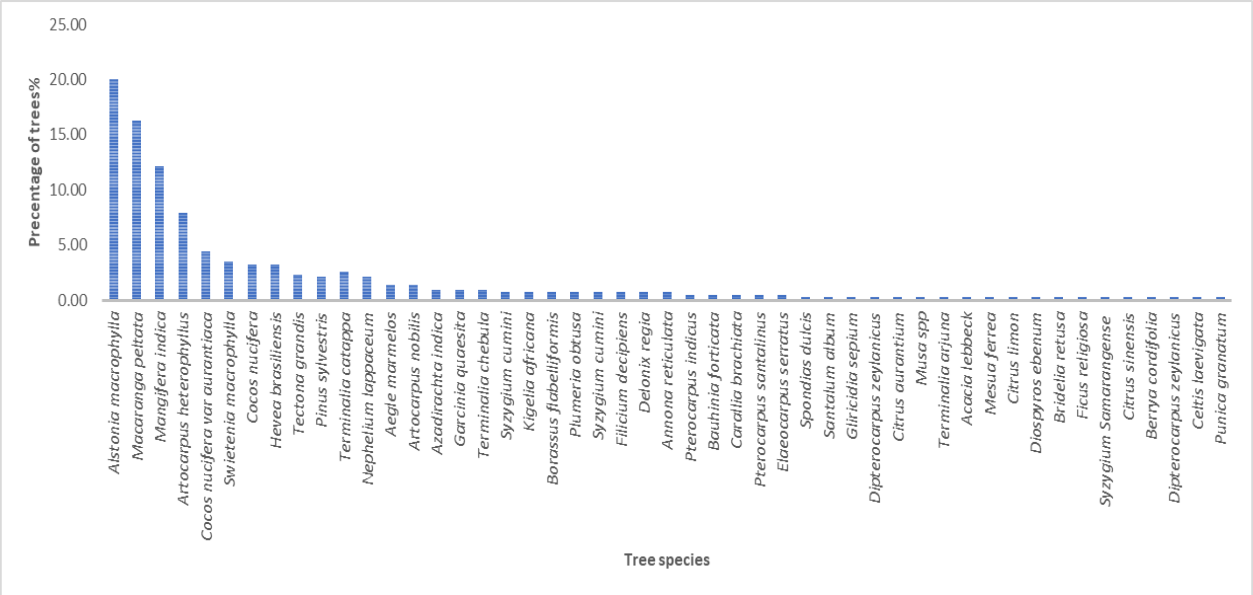

Fig 5: Tree species distribution

The total carbon sequestration potential for the SLTC campus was estimated at 442.90 tons of carbon. The most dominant species in terms of carbon sequestration potential are *Mangifera indica* (33.06ton) and *Caryota urens* (19.58ton) represent 52.64% of the carbon sequestered by trees in the study area (Fig 6). The next species, such as *Alstonia macrophylla*, *Macaranga peltate*, and *Artocarpus heterophyllus*, account for 19.82% of total carbon. However, the remaining 44 species accounted for 27.54% of total carbon sequestration.

86 *Alstonia macrophylla* trees sequester 24.52 tons of carbon, whereas three *Kigelia africana* trees contribute 7.94 tons. The average carbon sequestration rate of a single *Kigelia africana* tree is 41.6 times greater than that of an *Alstonia macrophylla* tree. These findings underscore the importance of selecting tree species with higher carbon accumulation potential for climate change mitigation.

Among the native tree species evaluated, *Terminalia chebula* exhibited the second-highest mean carbon content at 142.64 tons of carbon. Other notable species included.

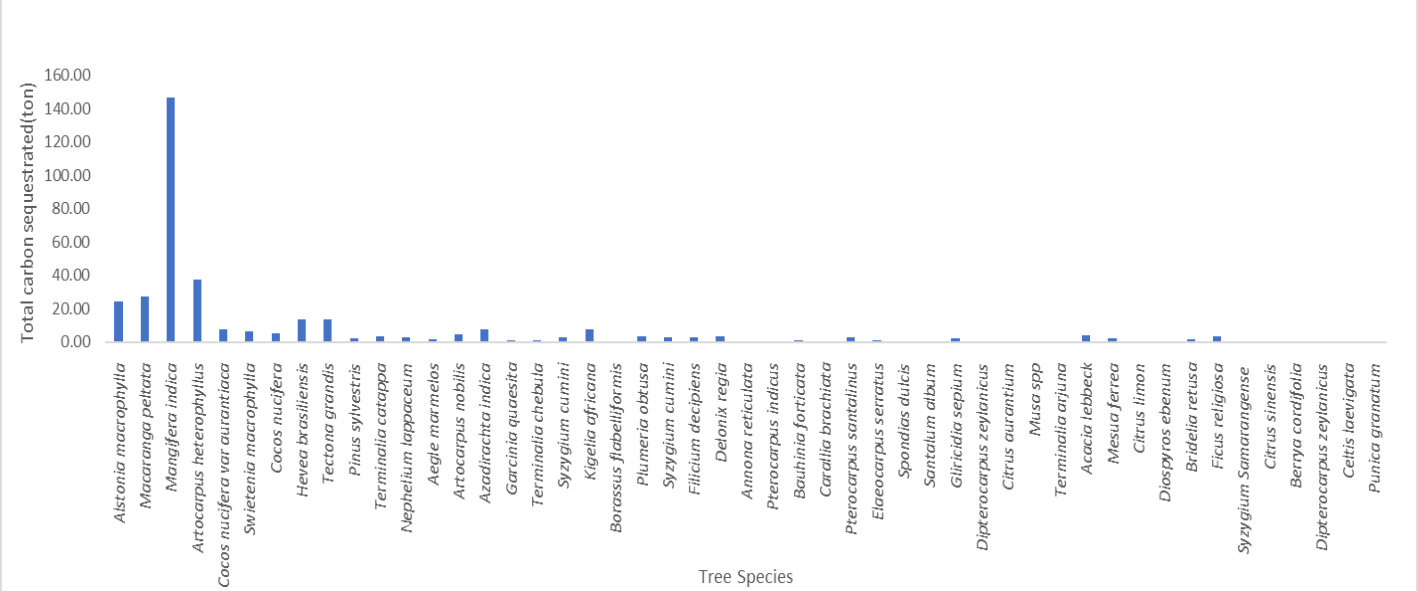

Fig 6: Total carbon sequestrated per tree species.

Kigelia africana (243.05 ton), *Acacia lebbeck*(207.53 ton) and *Azadirachta indica* (151.68 ton) were found as tree species with the highest mean carbon sequestration potential(Fig 7). Among the native tree species evaluated, *Terminalia chebula* exhibited the second-highest mean carbon content at 142.64 tons of carbon (Table 1).

Syzygium cumini (58.06ton), *Tectona grandis*(47.65ton), *Mangifera indica* (43.87ton), *Artocarpus heterophyllus*(43.27ton) were identified as the tree species with higher levels of mean carbon content. This strategy represents a more effective and sustainable approach than reforestation efforts that focus on planting more species with lower carbon sequestration capabilities.

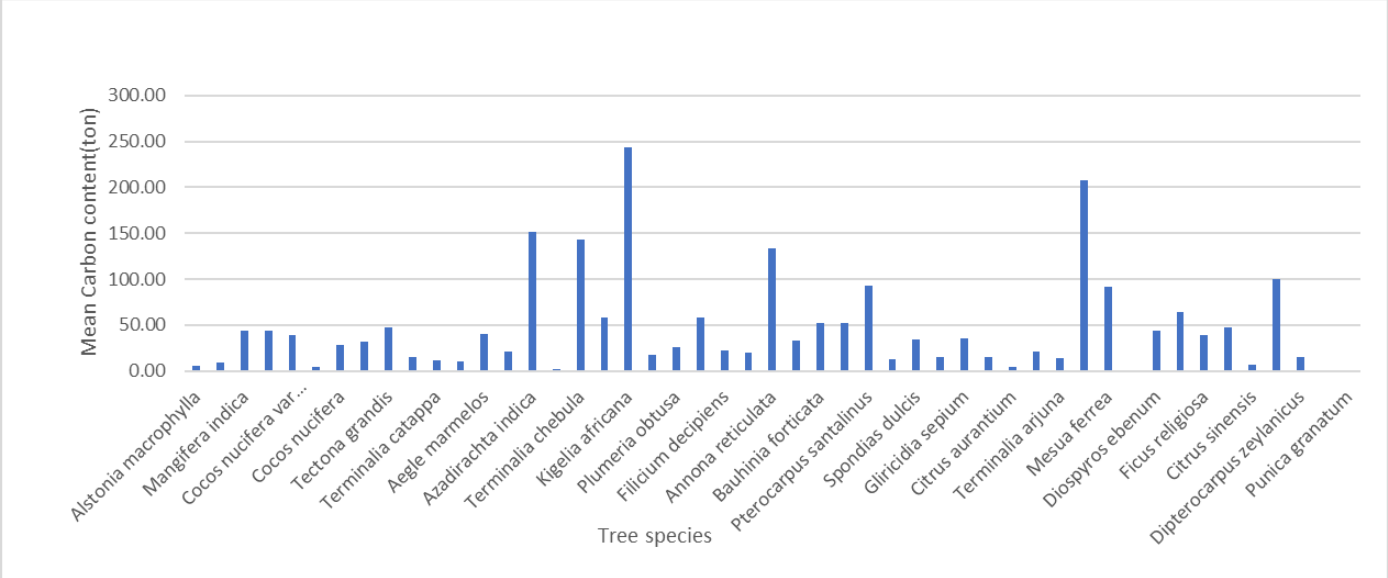

Fig 7: Mean carbon content of trees

These qualities make them ideal choices for landscaping projects in urban green spaces. All tree species in this study have similar characteristics such as low maintenance requirements, high survival rates, and adaptability to various weather conditions.

Trees can generally absorb approximately 45% to 51% of carbon during their wood formation [7]. Consequently, larger or taller trees tend to accumulate more biomass and carbon stocks than smaller ones [7]. Trees of considerable size, with a diameter exceeding 77 cm, can sequester approximately 90 times more carbon than smaller tree species, which typically have a diameter of less than 8 cm [8]. Moreover, larger trees can retain roughly 1000 times more carbon than their smaller counterparts [8]. Faster-growing trees may accumulate larger amounts of carbon in the early stage of their life. While the high specific gravity of slow-growing trees allows them to accumulate more carbon for longer [9].

This aligns with previous studies, such as the carbon sequestration assessment at Amity University in India which also found that larger tree species with extensive biomass, such as *Ficus religiosa* (Peepal Tree) and *Azadirachta indica* (Neem), are more effective in sequestering carbon [4]. *Mangifera indica*, *Ficus religiosa*, and *Azadirachta indica* show strong potential for effectively reducing air pollution over the long term, contributing to sustainable management and green ecological development [10].
The Shannon-Wiener Index for the study area was determined to be 2.91, reflecting a high level of biodiversity. To enhance this biodiversity further, it is critical to increase both species richness and evenness by promoting the abundance of native and endemic tree species while minimizing the presence of exotic species. The removal of invasive species, particularly *Alstonia macrophylla*, is essential for the preservation of local ecosystems. Initially introduced to Sri Lanka for its valuable timber, *Alstonia macrophylla* has since been classified as an invasive species, contributing to the degradation of primary forests [11].

Macaranga peltate (16.24%) recorded as the second most abundant species in the biodiversity assessment, is a prominent pioneer species that facilitates ecological restoration. Its rapid growth and effective seed dispersal enable it to quickly colonise disturbed areas, promoting soil stabilisation and contributing to habitat recovery [12]. The species plays a vital role in improving vegetation cover and supporting the overall resilience and regeneration of the ecosystem.

By promoting the planting of high-sequestration tree species and maintaining a diverse tree population, the campus contributes not only to reducing atmospheric CO_2 but also to biodiversity conservation and ecosystem Additionally, implementing strategies such as green walls and green rooftops can significantly enhance the university's carbon sequestration potential. These nature-based solutions not only increase vegetation cover but also contribute to reducing atmospheric CO_2 levels, improving microclimate regulation, and promoting biodiversity within the urban environment.

Table 1: Details of tree inventory

Common Name	**Scientific Name**	**Family**	**Number of Trees**	**Average height(m)**	**Average dbh(m)**	**Mean Carbon(ton)**
Devil Tree	*Alstonia macrophylla*	Apocynaceae	86	2.80	1.26	5.84
Macaranga	*Macaranga peltata*	Euphorbiaceae	70	3.52	1.27	8.81
Mango	*Mangifera indica*	Anacardiaceae	52	5.95	1.45	43.87
Jackfruit	*Artocarpus heterophyllus*	Moraceae	34	5.50	1.60	43.27
King Coconut	*Cocos nucifera var aurantiaca*	Arecaceae	19	8.40	0.85	39.19
Mahogany	*Swietenia macrophylla*	Meliaceae	15	1.85	1.59	4.66
Coconut	*Cocos nucifera*	Arecaceae	14	6.91	0.90	28.09
Rubber Tree	*Hevea brasiliensis*	Euphorbiaceae	14	4.60	1.88	31.61
Teak	*Tectona grandis*	Lamiaceae	10	6.90	1.32	47.65
	Pinus sylvestris	Pinaceae	9	5.05	0.90	15.12
Fishtail Palm	*Caryota urens*	Arecaceae	8	4.17	1.25	12.83
Tropical Almond	*Terminalia catappa*	Combretaceae	11	3.52	1.14	12.09
Rambutan	*Nephelium lappaceum*	Sapindaceae	9	3.06	1.15	9.93
Beli	*Aegle marmelos*	Rutaceae	6	8.73	0.57	40.26
Wal del	*Artocarpus*	Moraceae	6	4.18	1.37	21.32

	nobilis					
Neem	*Azadirachta indica*	Meliaceae	4	10.57	1.33	151.68
Goraka	*Garcinia quaesita*	Clusiaceae	4	1.04	1.52	1.61
Aralu	*Terminalia chebula*	Combretaceae	4	9.90	1.85	142.64
Java Plum	*Syzygium cumini*	Myrtaceae	3	6.51	1.23	58.06
Sausage Tree	*Kigelia africana*	Bignoniaceae	3	14.23	1.66	243.05
Palmyra Palm	*Borassus flabelliformis*	Arecaceae	3	6.53	0.46	17.96
Temple flower	*Plumeria obtusa*	Apocynaceae	3	6.03	0.97	25.59
Madan	*Syzygium cumini*	Myrtaceae	3	6.51	1.23	58.06
Phimbiya	*Filicium decipiens*	Sapindaceae	3	4.15	1.64	22.28
Mai tree	*Delonix regia*	Fabaceae	3	4.11	1.68	20.47
Anoda	*Annona reticulata*	Annonaceae	3	9.73	1.95	133.49
Wal Ehela	*Pterocarpus indicus*	Fabaceae	2	9.09	0.46	32.48
Orchid Tree	*Bauhinia forticata*	Fabaceae	2	8.79	0.79	52.16
-	*Carallia brachiata*	Rhizophoraceae	2	8.79	0.79	51.83
Red Sandalwood	*Pterocarpus santalinus*	Pterocarpus santalinus	2	6.07	1.74	92.71
Weralu	*Elaeocarpus serratus*	Elaeocarpaceae	2	3.41	1.57	12.96
Ambarella	*Spondias dulcis*	Anacardiaceae	1	7.16	1.02	34.37
Sandalwood	*Santalum album*	Santalaceae	1	6.49	0.30	14.95
Gliricidia	*Gliricidia sepium*	Fabaceae	1	4.42	2.54	35.88
Hora	*Dipterocarpus zeylanicus*	Dipterocarpaceae	1	3.90	1.13	15.25
Bitter Orange	*Citrus aurantium*	Rutaceae	1	4.54	0.26	4.23
Banana	*Musa spp*	Musaceae	1	9.93	0.41	21.26
Arjuna Tree	*Terminalia arjuna*	Combretaceae	1	4.60	0.66	13.45
Lebbeck Tree	*Acacia lebbeck*	Fabaceae	1	10.47	2.00	207.53
Ironwood	*Mesua ferrea*	Calophyllaceae	1	6.68	1.68	91.16
Lemon	*Citrus limon*	Rutaceae	1	1.65	0.22	0.35
Ebony	*Diospyros ebenum*	Ebenaceae	1	5.71	0.92	43.38
Ketakela	*Bridelia retusa*	Phyllanthaceae	1	7.25	1.70	64.61
Peepal Tree	*Ficus religiosa*	Moraceae	1	3.74	3.51	38.73
Java Apple	*Syzygium Samarangense*	Myrtaceae	1	10.77	0.37	47.96
Sweet Orange	*Citrus sinensis*	Rutaceae	1	3.71	0.59	6.41
Halmilla	*Berrya cordifolia*	Malvaceae	1	13.53	0.57	99.46
Kiripalu	*Dipterocarpus zeylanicus*	Dipterocarpaceae	1	3.90	1.13	15.25
Sugarberry	*Celtis laevigata*	Cannabaceae	1	1.72	0.20	0.49
Delum	*Punica granatum*	Punicaceae	1	1.36	0.17	0.23

Moreover, the findings indicate the need to regularly monitor tree health and growth to sustain the carbon sequestration benefits over time. Similar recommendations have been made in studies assessing carbon sequestration in semi-urban areas,ongoing assessment of tree growth and biomass is necessary to maximize environmental benefits [8].

According to a study done in 2022 on the campus, the carbon footprint accounted for 196.89 metric tons of CO_2e, with the majority attributed to the indirect emissions of the campus under scopes 01 and 02 [13]. collectively sequestered approximately 442.9 tons of carbon in the present study, revealing important insights into the role of urban forests in offsetting carbon emissions and promoting sustainability within campus environments. The carbon

sequestration capacity is more than double the university's annual carbon footprint, implying that the campus trees could theoretically neutralize. However, the annual sequestration rate would be a fraction of this total figure, depending on tree species, age, and growth conditions. Therefore, while the overall sequestration potential is impressive, the annual contribution of trees to carbon offsetting may not entirely neutralize yearly emissions.

IV. Conclusion

This study has highlighted the significant carbon sequestration potential of tree species within the SLTC Research University campus, with a total of 442.90 5 tons of carbon sequestered by the inventoried trees. Species such as *Alstonia macrophylla* (Devil Tree), *Mangifera indica* (Mango), *and Azadirachta indica* (Neem) were identified as the most dominant species. *Kigelia Africana* and, *Acacia lebbeck* were identified as the tree species with the highest carbon sequestration potential. The results also demonstrated that larger trees, particularly those with extensive biomass and high growth rates, were the most effective at sequestering carbon. Preserving these mature trees and promoting the planting of high-sequestration species will be essential to enhancing the campus's carbon sink capacity and contributing to Sri Lanka's broader climate mitigation goals. The highest abundance of invasive species, such as *Alstonia macrophylla*, over native species indicates ecosystem degradation. So, these invasive plants should be gradually replaced with planting more native-high carbon sequestrating native tree species, including *Terminalia chebula*, *Syzygium cumini*, *Tectona grandis*, *Mangifera indica*, and *Artocarpus heterophyllus*. This study provides valuable insights for similar carbon sequestration initiatives in other academic institutions and urban areas. By implementing strategic planning programs, preserving biodiversity, and promoting sustainable land use, campuses can significantly contribute to climate change mitigation efforts. Furthermore, the findings underscore the importance of regular monitoring to assess long-term carbon sequestration benefits and the role of universities as leaders in environmental sustainability.

References

[1] Anantsuksomsri, S., Positlimpakul, K., Chatakul, P., Janpathompong, D., Chen, G., & Tontisirin, N. (2024). Carbon sequestration analysis of the university campuses in the Bangkok Metropolitan Region. Journal of Infrastructure, Policy and Development, 8(6), 3385.

[2] Paredes-Canencio, K. N., Lasso, A., Castrillon, R., Vidal-Medina, J. R., & Quispe, E. C. (2024). Carbon footprint of higher education institutions. *Environment, Development and Sustainability*, 1-34.

[3] Leal Filho, W., Weissenberger, S., Luetz, J. M., Sierra, J., Simon Rampasso, I., Sharifi, A., ... & Kovaleva, M. (2023). Towards a greater engagement of universities in addressing climate change challenges. *Scientific reports*, *13*(1), 19030.

[4] Sharma, R., Pradhan, L., Kumari, M. and Bhattacharya, P. (2020). Assessment of Carbon Sequestration Potential of Tree Species in Amity University Campus Noida. Environmental Sciences Proceedings, [online] 3(1), p.52. doi:https://doi.org/10.3390/IECF2020-08075.

[5] Hassan, N., Hashim, I. C., Hashim, H., Abdullah, S., & Ali, W. N. A. W. (2023). Distribution, Estimation of Carbon Storage and Sequestration of Pelthoporum pterocarpum Species: A Case Study of Universiti Teknologi MARA, Seri Iskandar Green Campus. *International Journal of Business and Technology Management*, *5*(S3), 116-128.

[6] Bada, B. S., Oyegbami, I. E., Adeofun, C. O., Soaga, J. A., Adedeji, O. H., & Towolawi,
A. T. (2018). Carbon sequestration of urban trees along selected roads in Abeokuta, Ogun
State, Nigeria. Journal of Sustainable Technology, 9(2), 67-77.

[7] Ragula, A., & Chandra, K. K. (2020). Tree species suitable for roadside afforestation and
carbon sequestration in Bilaspur, India. Carbon Management, 11(4), 369-380.

[8] Vasagadekar, P.R., Gargate, A.V., Patil, Y.Y. and Raut, P.D. (2023). Carbon sequestration potential of trees from urban green spaces of Kolhapur city, Maharashtra, India. Environmental & Socio-Economic Studies, 11(3), pp.22–32. doi:https://doi.org/10.2478/environ-2023-0014

[9] Srinivas, N., Gopamma, D., & Jagadeeswara, R. K. (2014). Urban trees for carbon sequestration and management of climate change & disasters. International Journal of Research in Engineering and Technology, 3(16), 182-184.

[10] Jayawardhane, J., & Gunaratne, A. M. T. A. (2022). Influence Of Alstonia Macrophylla Spread On The Restoration Success Of Pine Conversion Programs In Sri Lanka. *Journal of Tropical Forest Science*, *34*(3), 285-295.

[11] Enitan, I. T., Durowoju, O. S., Edokpayi, J. N., & Odiyo, J. O. (2022). A review of air pollution mitigation approach using air pollution tolerance index (APTI) and anticipated performance index (API). *Atmosphere*, *13*(3), 374.

[12] Changkija, S., Thakuria, D., & Cynthia*, A. (2023). Traditional Use of Macaranga Trees for Soil Fertility: By Naga shifting cultivators in northeast India. In *Farmer Innovations and Best Practices by Shifting Cultivators in Asia-Pacific* (pp. 557-570). GB: CABI.

[13] Dilini, R. M. A., Jayawardana, H. A. D. A. K., & Liyanage, L. A. W. A. C. (2023). Quantifying Carbon Footprints within Higher Education Institutions: A Case Study of Sri Lanka Technological Campus.

Effect of Different Organic Manures and Organic NPK on Growth and Yield of Radish (*Raphanus sativus L.*)

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***Abstract*- This research investigates the influence of different organic manures and an organic NPK mixture on the growth and yield of radish (*Raphanus sativus* L.). Radishes are known for their nutritional benefits and are widely consumed across the globe. However, the use of synthetic fertilizers has led to concerns regarding soil health and environmental sustainability. This study was conducted to explore organic alternatives and develop sustainable cultivation practices. The experiment was designed using a randomized complete block design (RCBD) with seven treatments, including a control, and five replications. The treatments include compost, paddy compost, bonemeal, neem cake, vermicompost, and rice husk charcoal, combined with an organic NPK mixture made from dry tea dust, eggshell dust, and banana peels. Data were collected on various growth parameters, including plant height, leaf size, and root length, as well as yield parameters such as total biomass and fresh root weight. The results demonstrated that rice husk charcoal (T6) led to the highest yield and plant growth, whereas neem cake (T4) exhibited the lowest results. The research findings emphasize the potential of organic manures, particularly rice husk charcoal, combined with organic NPK, to enhance radish cultivation, offering insights into eco-friendly farming practices. Future studies are recommended to investigate the long-term effects on soil health and expand to other crops.**

Keywords – Radish, Organic Manures, Organic NPK, Sustainable Agriculture, Growth, Yield

I. INTRODUCTION

Radish (*Raphanus sativus L.*), a member of the Cruciferae family, is cultivated primarily during the Rabi season for its nutritional value and medicinal properties. The edible portion, developed from the primary root and hypocotyls, is rich in potassium and calcium, while its leaves provide essential vitamins and minerals such as vitamins A and C. The pungency of radish is attributed to volatile isothiocyanates [1]. To optimize radish growth and improve yield, research emphasizes the importance of balanced fertilizer management. Studies have shown that combining organic and inorganic fertilizers improves both radish production and soil health [2]. Although organic manures are bulky and have low nutrient content, they significantly improve soil health, structure, and water retention, especially in sandy loam soils [3,4].

Radish, with its short maturity period and adaptability, has drawn attention from researchers for its potential yield improvements through organic farming. Organic manures and NPK formulations offer sustainable alternatives to synthetic fertilizers, supporting the growing demand for organic produce [5].

II. PROBLEM STATEMENT

This study investigates the effect of different organic manures and an organic NPK mixture on the growth and yield of radish *(Raphanus sativus L.)*. With increasing concerns about the environmental impacts of synthetic fertilizers, the research aims to explore organic alternatives to enhance sustainable farming practices.

III. METHODOLOGY

The experiment was conducted in a polytunnel at SLTC Research University, Padukka, Sri Lanka, from June 2024 to August 2024. Radish seeds *(Raphanus sativus L.)* were planted in grow bags filled with a mixture of topsoil, sand, and different organic manures. Seven treatments were executed: T0 (Control): topsoil + sand (1:1); T1: Compost (50%) + topsoil (25%) + sand (25%); T2: Paddy compost (50%) + topsoil (25%) + sand (25%); T3: Bone meal (50%) + topsoil (25%) + sand (25%); T4: Neem cake (50%) + topsoil (25%) + sand (25%); T5: Vermicompost (50%) + topsoil (25%) + sand (25%); and T6: Rice husk charcoal (50%) + topsoil (25%) + sand (25%). Organic NPK (dry tea dust, eggshell dust, and banana peel in a 1:1:1 ratio) was applied as a top dressing to all treatments every two weeks except the control (recommended dose fertilizer).

Plant height (cm), number of leaves, leaf length (cm), root length (cm), root diameter (cm), and total biomass (g) were recorded at 30, 45, and 65 days after planting. The watering schedule and manure application were done based on plant

requirements, and respective fertilizer media were added again for each treatment 10, 30, and 40 days after planting. EM solution (1:1000) was applied every two weeks, and neem oil was sprayed as an insecticide. Radishes were harvested at maturity, and growth and yield data were analyzed using ANOVA. The study utilized a Randomized Complete Block Design (RCBD) with five replications per treatment.

IV. MONITORING AND DATA COLLECTION

Throughout the experiment, the growth and yield parameters of radish were systematically monitored and recorded at regular intervals to ensure comprehensive data collection. Growth parameters, including plant height, number of leaves, and leaf length, were measured at 30, 45, and 65 days after planting to assess the vegetative development of the radish plants. Leaf area was calculated using the formula.

Yield parameters were collected at the time of harvest. These included root length, root diameter, and total biomass. Roots and leaves were carefully harvested, weighed for fresh weight, and then dried in an oven at 105 °C for 8 hours to determine the dry matter content. Total biomass was calculated as the sum of dry root and shoot weights, providing an overall measure of plant productivity. The data were analyzed using ANOVA to evaluate the significance of treatment effects on growth and yield parameters, allowing for a detailed comparison of the effectiveness of the various organic manures and organic NPK on radish cultivation.

V. RESULTS

A. *Plant Height:*

- The control group demonstrated steady growth, with a height increase from 15.31 cm at 30 days to 33.32 cm at 65 days.
- Treatment T6 outperformed other treatments with a peak height of 26.72 cm at 45 days, although it was not significantly different from the control at 65 days (32.32 cm).
- T3 exhibited the highest height at 65 days (35.11 cm), suggesting its delayed but significantly highest compared to other treatments.
- T4 consistently had the lowest height (31.55 cm), indicating it may be less effective in promoting height growth. (Figure I)

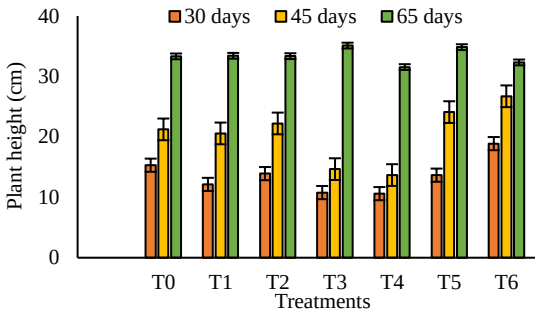

FIGURE I: RESULTS OF PLANT HEIGHT

B. *Number of Leaves:*

- The control group produced a higher number of leaves over time, with 22.4 leaves by 65 days.
- T6 yielded a similar leaf count at 45 days (13.4) but showed reduced leaf numbers at 65 days compared to the control (21.4).
- T5 was remarkable, with a sharp increase in leaves, peaking at 28.7 by 65 days, showing a potential boost in foliage production due to this treatment.
- T3 (19.2) and T4 (18.6) consistently produced significantly fewer leaves than other retirements, which may suggest these treatments suppress leaf formation. (Figure II)

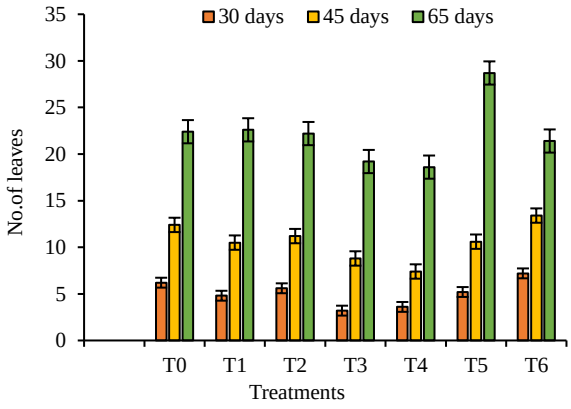

FIGURE II: RESULTS OF THE NUMBER OF LEAVES

C. *Leaf Length:*

- At 65 days, T0 (Control) had the longest leaf length at 27.24 cm, which was significantly different from the other treatments, indicating optimal growth. T6 with a leaf length of 26.65 cm, was not significantly different from T0.
- T5 showed consistent improvement over time, with its leaves reaching 26.18 cm by 65 days.
- T4 had the shortest leaf length (24.44cm) throughout the study period. (Figure III).

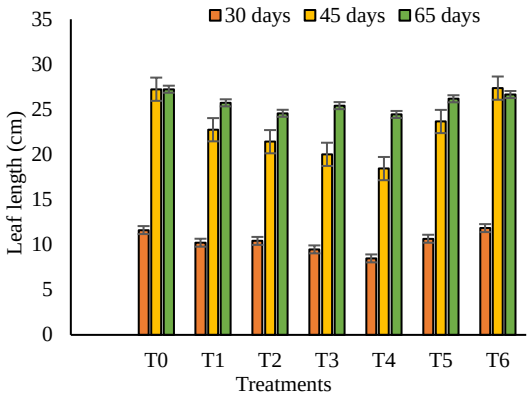

FIGURE III: RESULTS OF LEAF LENGTH

D. Root Length and Diameter

- Control and T6 produced the longest and thickest roots, with T6 showing a root length of 20.62 cm and a diameter of 3.62 cm, closely following the control.
- T4 (Neem Cake): Performed the worst in terms of root development, with root length and diameter being 6.38 cm and 1.61 cm, respectively.
- T5: Vermicompost contributed to a decent root length of 15.05 cm, but still did not match the performance of the control or T6. (Figures IV and V)

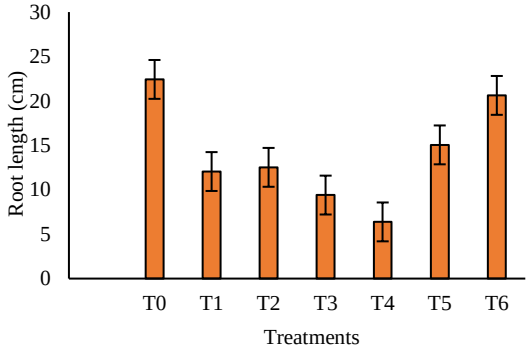

FIGURE IV: RESULTS OF ROOT LENGTH

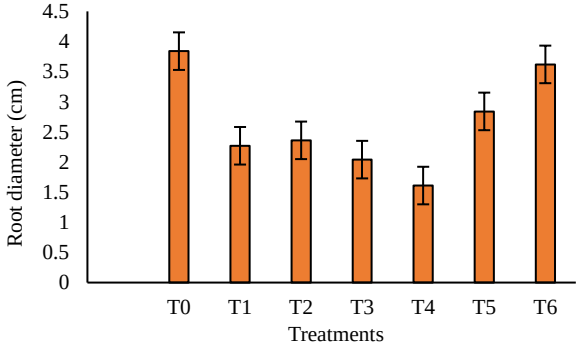

FIGURE V: RESULTS OF ROOT DIAMETER

E. Total Biomass:

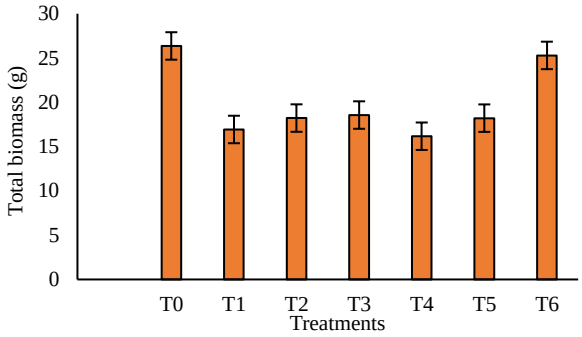

FIGURE VI. RESULTS OF TOTAL BIOMASS

- The control group achieved the highest biomass (26.36 g), closely followed by T6 (25.29 g), suggesting both treatments support better overall plant development.
- T3 also produced relatively high biomass (18.56 g), likely due to its effect on plant height and root structure.
- T4 had the lowest biomass values, suggesting these treatments negatively impact overall plant vigor. (Figure VI)

VI. DISCUSSION

The combination of compost with an organic NPK mixture made from dry tea dust, eggshell dust, and banana peels significantly improves plant growth by providing essential nutrients in a balanced form. T6 performed similarly to the control (T0) and proved to be the most effective organic manure in terms of height, leaf length, root development, and biomass. T4 consistently showed poor results across all growth and yield parameters, suggesting it is unsuitable for enhancing radish growth. Compost adds organic matter and beneficial microbes, while the NPK mixture supplies nitrogen, phosphorus, and potassium, ensuring steady nutrient release and enhanced soil fertility. Studies have shown that such organic waste materials can meet the minimum nutrient requirements for plant growth, supporting sustainability and reducing the environmental impact of chemical fertilizers [6]. The results of various organic fertilizer sources as combined solutions can increase the outputs (yield) compared to the standard fertilizing procedures [7, 8]. When combined with bonemeal, this mixture promotes root development, flowering, fruiting, and disease resistance, leading to higher yields and better soil health [9]. Using organic fertilizer solution with the combination of pineapple peel, fish, and shrimp wastes for hydroponic cultivation has resulted in the highest plant growth rate compared to commercial chemical fertilizers [10]. Similarly, adding vermicompost enhances the nutrient supply and creates a sustainable, nutrient-dense medium for healthier plant growth and increased productivity [11]. Finally, incorporating rice husk charcoal with the NPK mixture boosts soil fertility and crop yield by retaining and

gradually releasing nutrients throughout the plant's growth cycle, contributing to higher productivity and long-term soil health [12]. The use of Effective Microorganism (EM) solutions, such as EM4, in combination with organic fertilizers significantly enhances agricultural sustainability by improving soil fertility, promoting plant growth, and reducing the environmental impact. EM solutions accelerate the decomposition of organic matter and nutrient recycling, making nutrients more accessible to plants while boosting microbial activity in the soil. This leads to better soil structure, enhanced root development, and overall plant health. While EM solutions generally promote organic matter decomposition, there are instances where they may negatively affect root health by reducing beneficial fungal associations when combined with organic fertilizers [13]. Despite this, the combination of EM solutions with organic fertilizers offers a sustainable alternative to chemical inputs by improving composting efficiency and contributing to environmentally friendly farming practices [12, 13]. Based on the results, rice husk charcoal can be recommended as a sustainable organic alternative to synthetic fertilizers due to its strong performance in plant height, root development, and overall biomass. Neem cake, while used in some organic farming systems, may not be suitable for radish cultivation and requires further investigation or may be better suited for crops with different nutrient demands. Vermicompost shows promise for increasing leaf production and could be useful in systems where foliage growth is essential. Future research should focus on the long-term soil health impacts of rice husk charcoal and explore the potential of mixing neem cake with other fertilizers to enhance its efficacy.

VII. CONCLUSION

The results indicate that T6 (Rice Husk Charcoal), closely followed by the control, provides the most favorable conditions for radish growth, leading to higher yield and better plant development. Treatments like T3 (Bone Meal) and T5 (Vermicompost) also showed potential, particularly in enhancing plant height and leaf production, though they fell short in overall biomass. T4 (Neem Cake) consistently underperformed across all parameters, suggesting it may not be suitable for optimizing radish growth.

These findings underscore the importance of selecting appropriate organic manures and organic NPK formulations to enhance radish cultivation. The positive results from rice husk charcoal highlight its potential as a sustainable alternative to synthetic fertilizers. Further studies could explore long-term effects on soil health and evaluate these treatments across different crops.

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REFERENCES

[1] Yalwalker, K.S., Agrwal, J.P. and Bokde, S. *Manures and fertilizer-Agri- Horticultural Publishing House*, Nagpur, 2007. 490010, India.

[2] Poonkodi, P., A. Angayarkanni, and D. Gokul. "*Effect of Inorganic Fertilizers and Organic Manures on the Growth and Yield of Radish (Raphanus sativus L.)*." J. Emerg. Technol. Innov. Res 6.5 (2019): 163.

[3] Gyewali, B., et al. *"Effect of different organic manures on growth, yield, and quality of radish (Raphanus Sativus)*." SAARC Journal of Agriculture 18.2 (2020): 101-114.

[4] Khatri, Keshar Bahadur, et al. "*The effects of different sources of organic manures in growth and yield of radish (Raphanus sativus L.)*." International Journal of Applied Sciences and Biotechnology 7.1 (2019): 39-42.

[5] Singh, S. P., Yadav, D. K., & Tripathi, P. (2016). *Organic NPK fertilizers and their effect on root crops*. Journal of Crop Nutrition, 15(1), 120-128.

[6] Gupta, C., Prakash, D., Gupta, S., & Nazareno, M. A. (2019). Role of vermicomposting in agricultural waste management. Sustainable green technologies for environmental management, 283-295.

[7] Wijesundara, W. M. T. I., M. M. J. Harshana, M. D. D. W. Jayathilaka, M. A. U. P. Munasinghe, H. K. S. P. Bandara, H. M. V. T. Jayamal, I. G. S. H. Bandara, R. M. S. H. Rathnayake. H. G. H. Madusanka, M. R. C. S. B. Alahakoon, M. A. P. Madushani, B. K. B. Kavinda, W. K. N. H. Wijesekara, K. A. C. G. Kodithuwakku, B. M. C. B. Balasooriya, J. T. L. Madushanka, D. D. N. Vibodhani, R. M. P. I. Rajapaksha, and R. M. S. M. B. Rathnayaka. (2023). Enhancing yield of Tomato (*Lycopersicon esculentum* Mill.) in Sri Lanka through organic fertilizer solutions. 3rd International Research Conference of Sri Lanka Technological Campus, Colombo, Sri Lanka.

[8] Rajapaksha, R. M. P. I., W. M. T. I. Wijesundara, M. M. J. Harshana, M. D. D. W. Jayathilaka, M. A. U. P. Munasinghe, H. K. S. P. Bandara, H. M. V. T. Jayamal, I. G. S. H. Bandara, R. M. S. H. Rathnayake. H. G. H. Madusanka, M. R. C. S. B. Alahakoon, M. A. P. Madushani, B. K. B. Kavinda, W. K. N. H. Wijesekara, K. A. C. G. Kodithuwakku, B. M. C. B. Balasooriya, J. T. L. Madushanka, D. D. N. Vibodhani, and R. M. S. M. B. Rathnayaka. (2024). Effect of organic fertilizer solutions on the growth and yield of Tomato (*Lycopersicon esculentum* Mill.). Organic Agriculture, PREPRINT (Version 1) available at Research Square [https://doi.org/10.21203/rs.3.rs-3870411/v1]

[9] Malek, K. Z. A., Razak, N. A. A., Rosman, M. S., & Saliman, M. H. (2021). Review on Organic Waste Materials in Value of Nitrogen, Phosphorus and Potassium. Multidisciplinary Applied Research and Innovation, 2(2), 23-29.

[10] Athukorala, A.H.D., C.S. De Silva, R. M. S. M. B. Rathnayaka, and S. De Silva, (2024). *Vrikshayurveda* concept of *Kunapa jala* as a cost-effective organic fertilizer solution for Hydroponics to grow Lettuce *(Grand Rapido), International Research Symposium on Traditional Medicine (AyurEx Colombo)*.

[11] Mon, W. W., & Ueno, H. (2024). Short-Term Effect of the Combined Application of Rice Husk Biochar and Organic and Inorganic

Fertilizers on Radish Growth and Nitrogen Use Efficiency. Plants, 13(17), 2376.

[12] Yuanita, F., Roby, R. R. M., & Faradilla, H. (2022). Physical and chemical properties of organic fertilizer from banana (Musa paradisiaca) leaf and stem with effective microorganism activators (EM4). IJISRT, 7, 1653-1657.

[13] Bzdyk, R. M., Olchowik, J., Studnicki, M., Oszako, T., Sikora, K., Szmidla, H., & Hilszczańska, D. (2018). *The impact of effective microorganisms (EM) and organic and mineral fertilizers on the growth and mycorrhizal colonization of Fagus sylvatica and Quercus robur seedlings in a bare-root nursery experiment.* Forests, 9(10), 597.

Fabrication of ZnO Nanowires Using Chemical Bath Deposition at Different pH Levels for High-Performance Humidity Sensors

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ABSTRACT

Zinc oxide (ZnO) nanowires (NWs) are promising for humidity sensing due to their high surface area, semiconducting properties, and ease of integration into electronic systems, with applications across fields like healthcare, agriculture, and semiconductor manufacturing. Effective humidity sensors require high sensitivity, fast response, and thermal stability, and Chemical Bath Deposition (CBD) offers a scalable method to synthesize ZnO NWs with controlled structural and morphological characteristics.

This study investigates the impact of bath solution pH on the structural, morphological, and humidity-sensing properties of ZnO nanowires (NWs). Synthesized on a seed layer via Jet Nebulizer Spray Pyrolysis, ZnO NWs were produced with pH levels ranging from 4 to 10. Characterization techniques, including X-ray diffraction (XRD), scanning electron microscopy (SEM), and UV-visible spectroscopy, were employed to analyze the nanowires. The results reveal how pH influences the properties of ZnO NWs, providing critical insights for enhancing their applications in humidity sensing.

Keywords— ZnO, nanowires(NWs), Chemical Bath Deposition(CBD)

INTRODUCTION

Zinc oxide (ZnO) is a versatile metal oxide with significant potential across various applications, including electronics, humidity sensing, gas sensing, ultraviolet photodetectors, and ethanol detection systems. ZnO nanowires (NWs) are particularly valued for their unique properties, including high surface area, semiconducting characteristics, and ease of integration into electronic systems, making them highly suitable for humidity sensing applications[1].

The fabrication method significantly influences the structural and morphological characteristics of ZnO NWs, which directly affect their sensing performance. Chemical bath deposition (CBD) is an effective and scalable technique that enables precise control over the growth parameters of ZnO NWs. This study aims to optimize the CBD process for ZnO NWs to enhance their humidity-sensing capabilities at different pH levels. We investigate various deposition conditions, including bath composition and duration, and assess the impact of these parameters on the morphology, crystallinity, and overall performance of the NWs in humidity sensing applications [2] .

Humidity sensors are essential in various industries and have a significant impact on the global economy. Their performance has improved considerably over time, particularly in sectors like semiconductor manufacturing, healthcare, and agriculture, where they are used to monitor processes such as wafer production, respiratory functions, and soil moisture. The ideal humidity sensor should feature high sensitivity, thermal stability, and fast response, with different types such as humidity-sensitive resistors and capacitors being developed to meet these requirements [1].

METHODOLOGY

Preparation of ZnO seed layers

The ZnO seed solution was prepared by mixing 0.1 M solutions of zinc acetate dihydrate [$(Zn(CH_3COO)_2 \cdot 2H_2O)$,<99.5%] and monoethanolamine (MEA) [$NH_2CH_2CH_2OH$] in a 1:1 molar ratio. The mixture was sonicated for 15 min and was stirred at 300 rpm for 2 hours at 70°C. After stirring, the solution was allowed to age for 24 hours at room temperature. The aged solution was then spray-coated onto cleaned glass substrates, followed by annealing in air at 300°C for 1 hour.

Preparation of ZnO NWs

ZnO NWs were synthesized using an equimolar aqueous solution containing 0.1 M zinc nitrate hexahydrate [$Zn(NO_3)_2 \cdot 6H_2O$, 99.5%] and hexamethylenetetramine (HMTA) [$C_6H_{12}N_4$, 99.5%]. The substrates, pre-coated with seed layers, were subjected to chemical bath deposition (CBD) at 90 °C with a stirring rate of 700 rpm.

Characterization Techniques

Structural characterization was done using razing incident X-ray diffraction (GIXRD) using a Bruker D8 Advance system with Cu Kα radiation (λ = 1.5406 Å, 2θ = 20° to 80°). Morphology of the samples were analyzed using a Zeiss EVO LS 15 field emission scanning electron microscope (FE-SEM). Optical properties were characterized using a Shimadzu UV-1800 double-beam spectrophotometer.

Humidity sensing was assessed for a single optimized sample at one resistance level. The humidity measurements were conducted using a laboratory-prepared machine from an external source, not affiliated with the University[3]. Commercially available DHT22 module (Accuracy ± 2% RH, sensitivity 0.1% RH, hysteresis ± 0.3% RH, response time 2 s)., temperature and humidity sensor was used as the reference sensor. The impedance of the fabricated sensor was measured using electro-chemical impedance spectroscopy (EIS) with an AUTOLAB-PGSTAT302N instrument. Additional studies are currently underway.

RESULTS

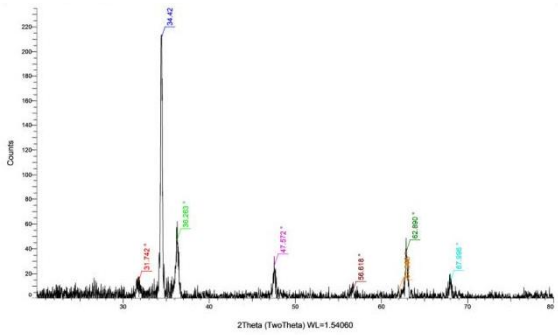
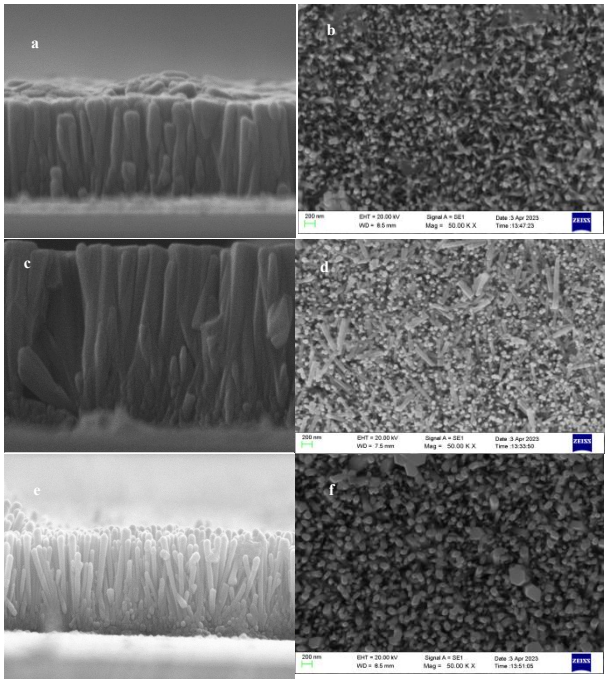


Fig.1 SEM image of ZnO nanowires grown by CBD

Fig. 1 indicates the diffraction pattern of the hexagonal ZnO phase structure, which is aligned with JCPDS No. 36-1451.The most prominent peaks for hexagonal ZnO NWs were observed at the (100), (002), and (101) planes, corresponding to 31.8°, 34.43°, and 36.24° - 2θ values , respectively. Among these, the (002) peak was the most pronounced, indicating the vertical alignment of the nanowires.



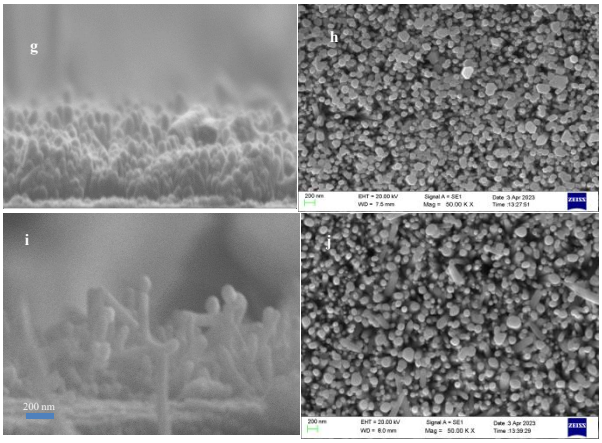


Fig 2 : SEM images of (a) & (b) at pH=4, (c) & (d) at pH=6, (e) & (f) at pH=6.5, (g) & (h) at pH=7, (1) & (j) at pH=10 for cross section and morphology, respectively

Table 01: Calculated values for average height, average width, and aspect ratio and band Gap values for corresponding pH

pH	Average height/nm	Average width/ nm	Aspect ratio (height/width)	Band Gap / eV
4	1209.54	169..7	7.127	3.067
6	750.98	114.87	6.537	3.21
6.5	1100.39	107.04	10.280	3.28
7	237.89	82.05	2.899	2.79
8	443.85	142.72	3.11	2.91
10	413.41	109.01	3.792	2.84

Thin films with high band gap values are effective for humidity sensing primarily due to their superior electronic and optical properties [4]. Also it has the highest aspect ratio and highest band thin film fabricated at initial pH solution at 6.5 was used to study the humidity sensing.

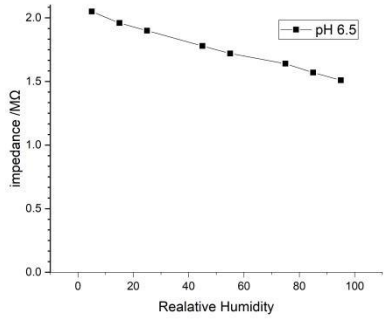


Fig 3 . The figuer of graph of Relative Humidity vs Impedance at 10 km for material fabricated at initial pH = 6.5

In this figure, as the humidity level increases, there is a general trend of decreasing impedance. The reduction in impedance with increasing relative humidity for ZnO thin films is due to the enhanced surface conductivity caused by water molecule adsorption and ionization, which increases the number of charge carriers. So, fabricated sensor material shows a good humidity sensing performance.

CONCLUSIONS

Hexagonal ZnO NWs were successfully deposited on borosilicate substrates using the chemical bath deposition technique. As the pH of the solution increased, the diameter, length, and aspect ratio of the NWs grew up to pH 6.5, but decreased after pH 6.5. At the pH= 6.5 has the highest Height : Width ratio and band gap value. Also it show the high absorption of water molecules at lower humidity level.

ACKNOWLEDGMENT

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REFERENCES

[1] S.A. Kamaln, N.D. Md Sin, M.H. Mamat, M.Z. Hussain, N.A. Asli, and M.F. Maleik, " A Review of Zinc Oxide(ZnO) Nanostructure Based Humidity Sensor," Int. J. Nanosci. Nanotechnol., vol.19, pp 85-95, June 2023.

[2] F. Li., L. Peng., and Z. Hongyan., "Preparation and Research of a High-Performance ZnO/SnO2 Humidity Sensor", Sensors, vol 22., Dec 2022, doi: 10.3390/ s22010293J.

[3] M.D. Maduwantha., H. Galagedra., Y.Y. Kannangara., S. Karunarathne., M.M.M.G.P.G., Manthilaka., H.C.S. Perera., R. Mahadeva., S. Areya., R.M.G. Rajapakse., W.P.S.L. Wijesinghe., "Low-cost ZnO incorporated carbonized nitrile butadiene rubber (NBR) as arelative humidity monitoring sensor", Materials Science and Engineering B, vol 298, 116862, 2023

[4] C.A. Ku., C.K. Chung., " Advances in Humidity Nanosensors and Their Apllication: Review". Sensors, Vol. 23,2388, Feb 2023

Six-Key ASCII-Braille Converter with Real-Time Audio and Tactile Feedback for Visually Impaired Communities

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***Abstract*— This research introduces an innovative assistive technology aimed at enhancing communication for visually impaired people in Sri Lanka, particularly those who speak Sinhala and Tamil. The system addresses unique challenges, such as limited accessibility in existing communication tools for these languages. It integrates a six-key ASCII-Braille converter keyboard with a web application that provides tactile and audio feedback for real-time interaction. Users can efficiently input text, which is converted into ASCII-Braille characters for tactile reading. A servo motor automates the interaction with Braille cells, enhancing tactile output. The web application, built with Django and integrated with WebSockets, facilitates real-time communication through instant messaging and group chats, supporting Sinhala and Tamil languages. Additionally, the system utilizes Google Text-to-Speech for auditory feedback, promoting inclusivity for both visually impaired and sighted users. To improve efficiency, Huffman coding is applied to compress data by selecting 10 representative letters from each language, achieving 99% efficiency for Sinhala and 85% for Tamil. Wireshark analysis revealed a delay of approximately 1.32 seconds for input processing, with a minimal delay of 0.0003 seconds for message transmission, highlighting areas for enhancement to improve system responsiveness.**

Keywords— visually Impaired, braille Converter, real-Time Communication, sinhala, tamil

I. INTRODUCTION

In today's world technology plays a key role in improving the lives of people with visual impairments. However communication and accessibility are still major challenges, especially in countries like Sri Lanka where language diversity and limited technological access make things even harder. Many current assistive technologies don't fully meet the unique needs of visually impaired people, which often leads to communication barriers and limits their social integration. To address these challenges, this project is creating a complete solution that combines a six-key ASCII-Braille converter keyboard with a web application. The keyboard will help visually impaired users input in Braille using Sinhala and Tamil, providing real-time audio feedback through Google Text-to-Speech (gTTS) and converting text into ASCII-Braille characters for tactile reading. Using a servo motor, the project also provides an automated Braille output, ensuring accurate and consistent tactile feedback. The web application, built using Django and Django Channels, allows users to communicate in real time, with features like instant messaging and group chats, supporting Tamil and Sinhala languages. This will improve social interaction and connectivity while maintaining privacy and security. By integrating these tools, the project aims to enhance communication and promote social inclusion for visually impaired people in Sri Lanka. The combination of a tactile keyboard, audio support, and a web app aims to help users participate more actively in their everyday lives, fostering an accessible and inclusive environment.

According to the World Health Organization (WHO) estimates that around one billion people worldwide have disabilities, with approximately 285 million experiencing visual impairment. This includes 39 million people who are blind and 246 million who have low vision. Visual impairment is categorized into four levels: normal vision, moderate visual impairment, severe visual impairment, and blindness. The term" low vision" encompasses both moderate and severe visual impairments, along with blindness, covering all degrees of visual impairment. Globally, the primary causes of visual impairment are uncorrected refractive errors (43%), unoperated cataracts (33%), and glaucoma (2%). Among the 19 million visually impaired children, 12 million suffer from refractive errors, which are often correctable. Approximately 1.4 million children are irreversibly blind and need visual re-habilitation [1].

In Sri Lanka, about 1.7 million people have disabilities, with approximately 200,000 being blind and 400,000 having low vision. Cataracts are the leading cause of blindness, followed by refractive errors, glaucoma, and diabetic retinopathy. The country has 17 specialized schools for the deaf and blind and offers integrated education programs. Despite these efforts, many visually impaired people face difficulties accessing education and employment. Only 71% of the adult blind population has received formal education. Braille, a tactile writing system invented by Louis Braille in the 19th century, is designed to help blind and partially sighted people read and write by touch. It uses a set of six dots arranged in a 3x2 grid [2].

Although originally used on engraved paper technological advances have made it possible to use Braille with electronic devices. Traditional assistive tools like screen readers and Braille displays are helpful but often fail to address specific needs, particularly for real-time communication and language support. This can lead to feelings of isolation and decreased

independence. This project aims to bridge these gaps by developing a six-key ASCII-Braille converter keyboard and an integrated web application. These tools are designed to improve communication in Sinhala and Tamil enhancing the quality of life for visually impaired people in Sri Lanka.

II. Literature Review

Text entry on touchscreens is often difficult for people with visual impairments. Although advancements like screen readers have improved accessibility traditional keyboards still pose challenges. Braille Enter is designed to solve these issues by allowing users to input text using Braille on a touchscreen. It enables typing letters, numbers, and punctuation by pressing and tapping on the screen to represent Braille dots. Initial tests with blind users show that Braille Enter could make smartphones more accessible as it lets users type with just one finger [3].

Using computers and other digital devices is challenging for visually impaired people due to accessibility issues. A new Braille keypad has been developed to help with this. It uses six switches to represent Braille cells, allowing users to type text by pressing combinations of these switches. The keypad also includes text-to-speech functionality to confirm what was typed. This device helps visually impaired users interact with computers and mobile phones more easily [4].

Ramachandran et. al developed a new device to help people who are both deaf and blind. It is portable and low-cost, converting Braille to text for communication. It works for both short-distance (face-to-face) and long-distance communication. For short-distance, it uses a Braille keypad and an LCD display. For long-distance, it uses a GSM module to send messages. The device also includes a vibration alert for message notifications. This affordable solution aims to improve communication for people with Deaf-Blindness [5].

Braille displays help blind users access computers but are costly due to the technology involved. These devices typically have 8 to 80 cells, each representing a Braille character. Additionally, there's a lack of software tailored to accessibility needs. This study aims to develop an affordable system using one Braille cell along with software following U.S. accessibility standards. Early tests with blind volunteers show promising results for improving digital access [6].

Translating Braille to readable text has been challenging, especially for languages like Sinhala. In Sri Lanka visually impaired students and teachers struggle with the lack of Braille-to-Sinhala conversion tools. A new system addresses this by converting Braille text to Sinhala using optical character recognition. It identifies Braille symbols and translates them into Sinhala Unicode characters. This tool improves the accuracy and speed of translating Braille, making the educational process smoother for visually impaired students [7].

Padmavathi et.al presented a method for converting scanned Braille documents into text enabling audio playback through a speech synthesizer. The process involves preprocessing the documents to enhance dot visibility and reduce noise followed by segmenting Braille cells and extracting dot patterns to create a numerical sequence. These sequences are then mapped to corresponding letters in English, Hindi, and Tamil. Additionally the paper outlines a mechanism for typing Braille characters using a keyboard's number pad with the typed characters also being mapped to their respective alphabets for audio output [8]. Furthermore Tab. 1. describes the existing literature examined.

TABLE I. TABULAR FORM OF LITERATURE STUDIED

Title	Authors	Year	Key Findings
ASCII to Braille Converter using Embedded Systems	A. Sharma, R. Gupta [9]	2021	The device effectively translated text to Braille format for educational purposes
Braille Tutor System for Visually Impaired Learners	L. Nguyen, P. Khan [10]	2020	Improves learning speed and comprehension for visually impaired students
Real-Time ASCII to Braille Converter Using Machine Learning	H. Lee, K. Kim [11]	2023	Real-time conversion with 98% accuracy
Portable ASCII-Braille Converter with Refreshable Display	M. Al-Riyami, S. Haider [12]	2022	Developed a portable device that converts ASCII text to Braille using a refreshable Braille display
Smart Braille Converter and Reader for Visually Impaired	J. Thomas, E. Fernandez [13]	2019	Can read printed text and convert it into Braille

III. Methodology

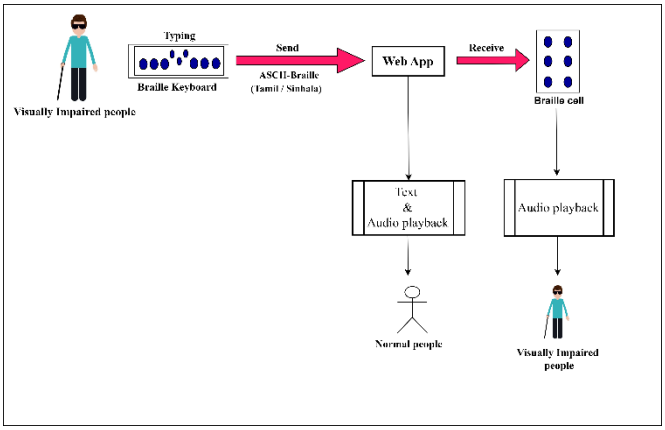

Fig 1. Architecture of the proposed system

The system's overall architecture which is intended to improve communication between visually impaired and non-visually impaired users is shown in fig. 1.

Users with visual impairments initiate the system by typing messages on a Braille keyboard. This keyboard supports both Tamil and Sinhala languages and is configured to translate inputs into ASCII-Braille format. After typing the message is transmitted to a web application over WebSocket communication guaranteeing instantaneous two-way communication between two people or systems. After

processing the ASCII-Braille code the web program converts the message into text. It also ensures that visually challenged users can hear the message by turning the text into auditory feedback before it is delivered. The visually challenged user can read the message through tactile means by relaying the message back to Braille cells simultaneously. The web application interface displays the message in standard text format for users who are not visually handicapped facilitating a smooth communication between the two parties.

A. Six-key ASCII-Braille converter keyboard

The Braille-bond system is a comprehensive solution aimed at improving communication for visually impaired people by integrating several innovative components. The first step is the creation of a six-key ASCII-Braille converter keyboard (see fig. 2(A)) which is intended to make entering Braille characters easily. By hitting different combinations of these keys' users can efficiently type Braille text. Each key on the keyboard represents a separate set of Braille dots. This design makes it easy for users to produce Brille text with accuracy and convenience.

The device integrates Braille cells with a custom-designed PCB board which manages connections between the Braille cells, push buttons, and a Raspberry Pi. The Raspberry Pi programmed using Thonny Python and VS Code enables real-time translation of keyboard inputs into Braille offering a tactile reading experience. Servo motors are also used to interact with the Braille cells.

The Braille-bond technology is distinct in that it uses a servo motor to deliver tactile feedback. The Braille characters that the user types are physically represented by Braille cells (fig. 2(B)) driven by this motor (fig. 2(C)). By offering a tactile output the system allows users to feel the Brille text they have input creating a more interactive and tangible communication experience. This feature is very helpful for people who read and comprehend text by touch. Furthermore, the system investigates the use of Huffman coding for data compression aiming to make data handling more efficient.

Overall the Braille-bond system combines tactile feedback, real-time communication capabilities, a feature-rich web application, a Braille keyboard (fig. 2(D), and possible advancements in data compression. Together, these elements produce an intuitive instrument that improves visual impaired people's ability to communicate increasing the effectiveness and accessibility of their interactions.

B. Web application

The web application is designed to complement the six-key ASCII-Braille converter keyboard by providing real-time communication through Web Sockets (see fig 3. (A)&(B)). Developed with Django and JavaScript it features an accessible user interface and integrates Braille support allowing users to send and receive Braille-encoded messages. It also includes text-to-speech functionalities.

As in fig. 3. (C), three main options are available to the user to personalize the experience: role identification, language selection, and Braille cell output settings. Users can designate their status as either a Visually Impaired Person or a Normal Person and select English, Tamil, or Sinhala as their preferred language. Braille output and audio feedback are helpful for visually impaired users, while standard text-based communication is provided for normal users. When the ON/OFF switch is engaged, tactile feedback is made possible by controlling the Braille cell output.

The WebSocket architecture, which facilitates real-time communication between two web apps is depicted in fig. 4. Both programs are linked to Personal Computers (PCs) that interpret the messages using the WebSocket protocol after processing input from Six-key Braille Keyboard. Instantaneous message transfer is made possible with WebSocket communication allowing both visually impaired and non-impaired people to converse in real time. This technology maintains an ongoing connection between the client and server allowing for immediate and seamless message exchanges. Messages can be sent and received instantly. The technology facilitates inclusive and accessible communication for visually impaired users by combining audio feedback, real-time WebSocket communication, and Braille input. Through tactile or aural means the design guarantees effective conversation participation from people with visual impairments.

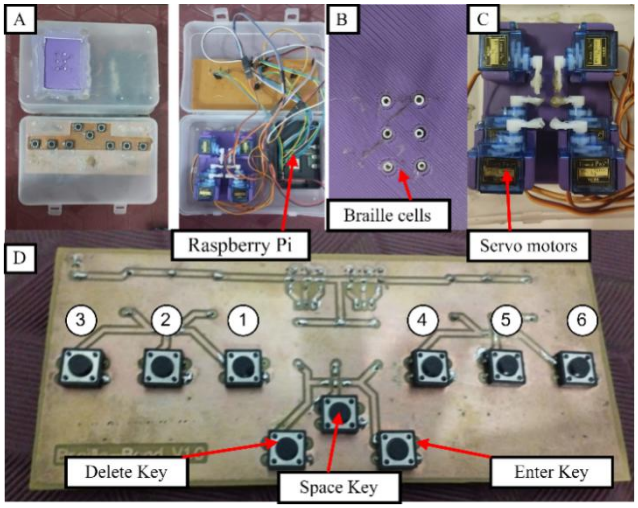

Fig. 2. (A) six-key ASCII-braille converter keyboard, (B) Braille cells, (C) Six servo motors, (D) Keyboard

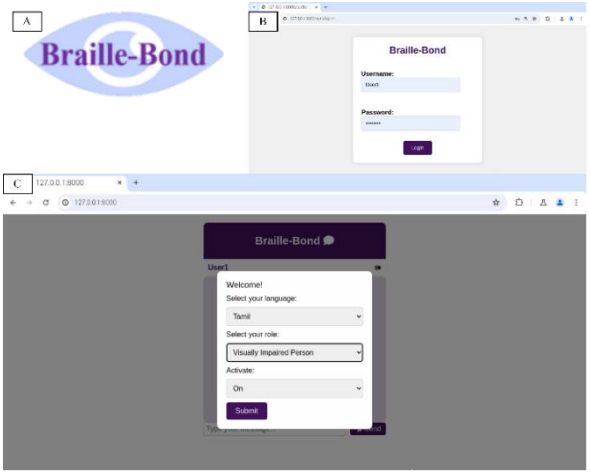

Fig. 3. (A) App logo, (B) Login page, (C) Select roles

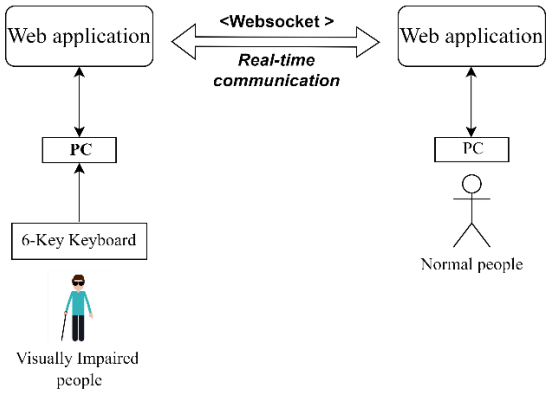

Fig. 4. Web Socket architecture

IV. Results and Discussion

The results and analysis of the suggested system are covered in this section.

1) WebSocket Communication

Web Sockets enable real-time bidirectional communication between web applications ensuring seamless live interaction. The flow diagram on fig. depicts how Web Sockets facilitate communication: one application connects to a PC equipped with a 6-Key Keyboard while another connects to a separate PC with WebSocket pathways establishing the connection between them. The WebSocket server is implemented using Django Channels which supports asynchronous WebSocket handling. The WebSocket client initiates connections and the AsyncWebsocketConsumer class manages WebSocket events. Upon connection, the consumer joins a designated group (e.g. "group chat") and manages the connection lifecycle including joining *(connect())* and leaving *(disconnect ())* the group. The *receive ()* function handles incoming messages by converting Braille to text using the braille to text *transliteration ()* method. After processing, the messages are forwarded to the group and provided as audio feedback to ensure accessibility. The *sendmessage()* function ensures that responses are sent back to the WebSocket client maintaining smooth and effective real-time communication (see fig. 5)

2) Process of message send and receive

System receives a message in either Tamil or Sinhala detects the language and processes it. The message encoded in binary format is decoded or converted by the system. The binary code is grouped to match specific characters. After processing the system translates the binary code back into the respective text and prepares the message for sending ensuring that the text has been successfully processed and is ready for communication (see fig. 6).

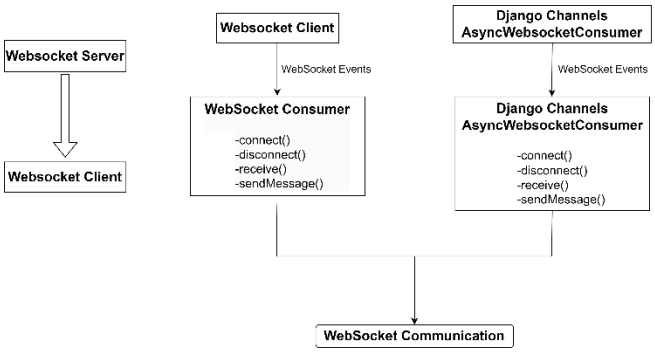

Fig. 5. WebSocket communication

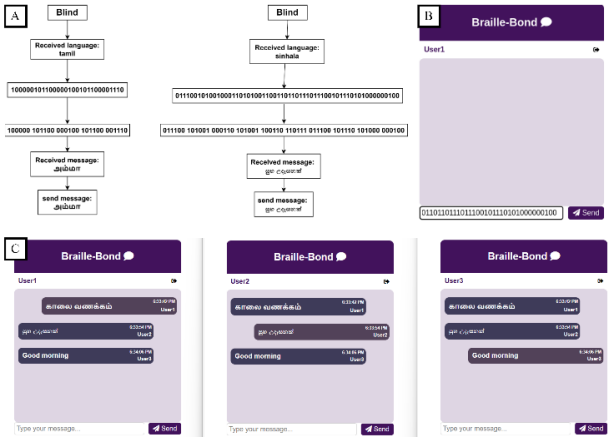

Fig. 6. (A) Binary conversion and processing, (B) Message Encoding in Binary, (C) Braille-Bond Interface: Tamil and Sinhala Translation

3) Compression Efficiency (Huffman Coding)

Huffman coding was applied for efficient data compression in Tamil and Sinhala languages. By selecting 10 representative letters from each language and assigning probabilities summing to 1.0 Huffman trees were constructed to generate optimal codes. This approach reduced the bit length for encoding phrases significantly-from 42 to 23 bits in Tamil and from 48 to 26 bits in Sinhala-demonstrating improved storage and transmission efficiency through effective use of language-specific probabilities (see fig. 8).

Huffman coding reveals that it could improve system performance as well. Specifically, it would enhance storage efficiency by minimizing the average bit length of messages, allowing for increased storage capacity. Additionally, it would facilitate faster data transmission, thereby reducing latency and improving responsiveness in real-time communication, resulting in smoother interactions for visually impaired users. Overall, these efficiencies could significantly enhance the system's performance.

a) For Sinhala language

$H(x) = \sum_{i=1}^{n} p(x_i) \log_b p(x_i)$

$= 3.18505$ bits

$L = \sum_{i=1}^{n} p(s)\, l(s_i) = 3.21$ bits

$(\eta) = \frac{H(x)}{L} = 99\%$

b) For Tamil language

$$H(x) = \sum_{i=1}^{n} p(x_i) \log_b p(x_i)$$
$$= 2.79307 \text{ bits}$$

$$L = \sum_{i=1}^{n} p(s)\, l(s_i) = 3.25 \text{ bits}$$

$$(\eta) = \frac{H(x)}{L} = 85\% \qquad (2)$$

Here in (1) and (2) it denotes the entropy *H(x)* of a discrete random variable x with possible outcomes x1, x2,…xn and corresponding probabilities p(x1), p(x2),…,p(xn) where $\log_b$ denotes the logarithm to the base b. The average code-word length L for a source with symbols S = {s1, s2, . . . , sn}, where each symbol s_i has a probability p(s_i) and is encoded with a codeword of length l(s_i). The efficiency η of a code is given by the entropy H(X) and the average codeword length L.

4) Wireshark Capture-Based Optimization

An analysis using Wireshark revealed a delay of approximately 1.32 seconds (see 3) between the application receiving input from the keyboard and generating a response. This delay significantly affects the application's responsiveness to user input. However, the internal delay between the application sending and receiving data was measured at just 0.0003 seconds (see 4) indicating minimal latency within the application itself. These results underscore the importance of optimizing input processing times to improve overall application performance and enhance the user experience (see fig. 9).

Delay time = App – Keyboard (3)
= (6.394346000s) – (5.074372000s)
= 1.319974s

Delay time = receive(app) – send(app) (4)
= (6.394646000s) – (6.394346000s)
= 0.0003s

Wireshark analysis indicated a delay of approximately 1.32 seconds (1320ms) in this application, which is significantly higher than typical delay ranges for various system types. Standard desktop applications usually experience delays of 50 to 200 ms, while web applications range from 100 to 300 ms. Real-time chat applications typically see delays between 20 and 100 ms, making this application's delay noteworthy. This delay may result from processing time on the Raspberry Pi, data conversion steps, or network latency over WebSocket. Conversely, the communication delay in this system for receiving and sending data was only 0.0003 seconds (0.3 ms), demonstrating exceptional efficiency compared to gaming applications (1-20 ms) and IoT devices (5-30 ms).

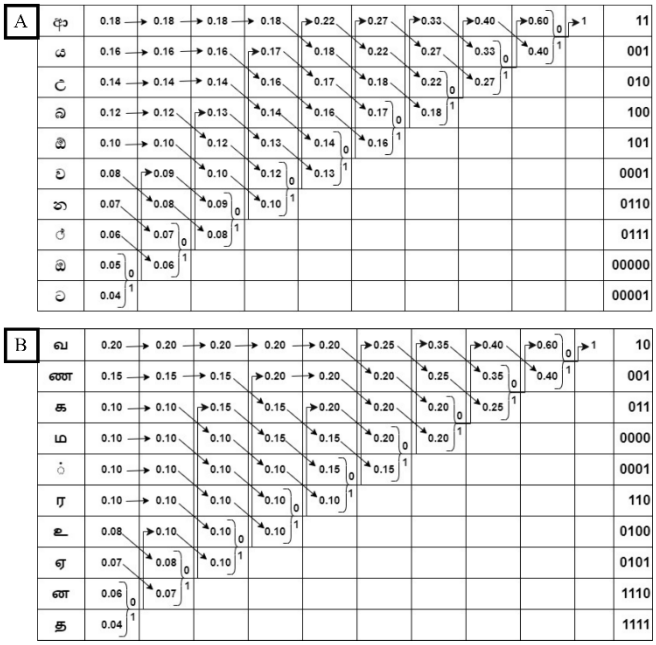

Fig. 7. (A) Huffman tree for sinhala, (B) Huffman tree for Tamil

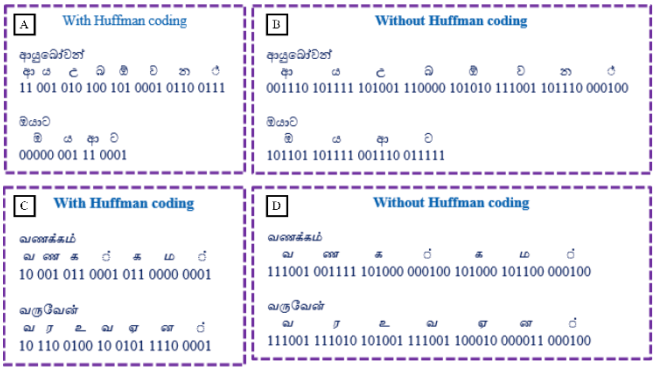

Fig. 8. Comparison between two languages with and without Huffman

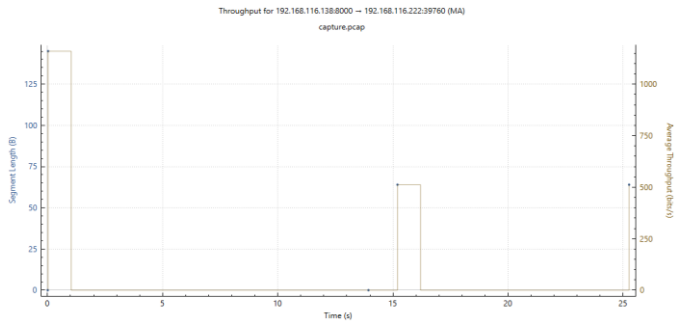

Fig. 9. Throughput graph

The results of this study demonstrated the effectiveness of integrating both tactile and auditory feedback in a single system aimed at enhancing communication for visually impaired users particularly those using Sinhala and Tamil languages. By combining a six-key ASCII-Braille converter keyboard with real-time messaging through a web application this solution offers a novel approach to addressing communication barriers for visually impaired people in Sri Lanka.

In comparison to previous systems, which focused primarily on either auditory feedback or text conversion the dual-output system in this project significantly enhances user

experience by providing real-time tactile feedback through servo motors controlling Braille cells. This makes it easier for users to verify their input immediately. Additionally the multilingual support covering both Sinhala and Tamil combined with privacy-focused design features such as auto-deletion of old messages addresses specific cultural and infrastructural challenges in the Sri Lankan context. This improves the social inclusion of visually impaired users ensuring their participation in digital communication platforms without compromising data security.

Future versions should prioritize reducing the processing latency between keyboard input and system response. Comprehensive feedback on how well the system fulfills the demands of visually impaired users in various real-world circumstances would also be obtained by performing thorough usability testing with a broader sample of these users. Reliability of the system could potentially be improved by implementing sophisticated error-detection techniques especially in areas where reliable internet connectivity is not assured.

The system's real-time communication, tactile and auditory feedback, and data compression techniques combine to create a reliable solution that can be modified for usage not only in Sri Lanka but also in other areas with comparable requirements. Through accessible digital communication this cutting-edge technology can greatly enhance the independence and quality of life of visually impaired people promoting more social integration.

V. Conclusion

In conclusion this research project provides an innovative solution for enhancing communication among visually impaired people particularly those speaking Tamil and Sinhala in Sri Lanka. By integrating a six-key ASCII-Braille converter keyboard with a web application the system offers a user-friendly and accessible communication platform. The combination of tactile feedback via a servo motor and real-time auditory feedback through Google Text-to-Speech (gTTS) ensures a seamless and intuitive experience for users. The implementation of Web sockets enables real-time messaging fostering rapid and efficient communication. Additionally multilingual support allows easy transitions between Tamil and Sinhala making the system versatile and inclusive. By employing Huffman coding for data compression, the project enhances efficiency optimizing both storage and transmission especially valuable in areas with limited internet bandwidth and storage capacity. Overall, this project provides a robust and comprehensive communication tool that significantly enhances the independence and social interaction of visually impaired people. Its unique features such as tactile input, auditory feedback, and data efficiency position it as a critical resource for improving the quality of life and promoting fuller engagement in everyday activities for the visually impaired community.

References

[1] World Health Organization, "Visual Impairment and Blindness Fact Sheet," 2021. [Online]. Available: https://www.who.int/news-room/fact-sheets/detail/blindness-and-visual-impairment. [Accessed: Sep. 30, 2024].

[2] Braille Authority of North America, "History of Braille," 2023. [Online]. Available: https://www.brailleauthority.org/history.html. [Accessed: Sep. 30, 2024].

[3] M. Alnfiai and S. Sampalli, "BrailleEnter: a touch screen braille text entry method for the blind," Procedia Computer Science, vol. 109, pp. 257–264, 2017. [Online]. Available: https://doi.org/10.1016/j.procs.2017.05.348

[4] L. Prabha, S. Ej, C. Samuel, and G. Ramesh, "Low-cost real-time braille keypad for communication," International Journal of Engineering & Technology, vol. 7, no. 77, pp. 10–14419, 2018. [Online]. Available: https://doi.org/10.14419/ijet.v7i1.20.9874

[5] S. Ramachandran, N. Rajan, K. N. Pallavi, J. Subashree, S. Suchithra, and B. Sonal, "Communication device for the visual and hearing-impaired persons to convert braille characters to English text," in 2021 International Conference on Emerging Smart Computing and Informatics (ESCI), 2021, pp. 587–592. [Online]. Available: https://doi.org/10.1109/ESCI50559.2021.9385082

[6] M. B. Schmidt, L. Gustavo, and A. R. García Ramírez, "Single braille cell," in 5th ISSNIP-IEEE Biosignals and Biorobotics Conference (BRC), 2014, pp. 1–5. [Online]. Available: https://doi.org/10.1109/BRC.2014.6881004

[7] K. V. S. D. Vithanage, "Braille to text convertor for Sinhala," Master's thesis, University of Colombo, Sri Lanka, 2021.

[8] S. Padmavathi, S. S. Reddy, D. Meenakshy, et al., "Conversion of braille to text in English, Hindi and Tamil languages," arXiv preprint arXiv:1307.2997, 2013. [Online]. Available: https://arxiv.org/abs/1307.2997

[9] A. Sharma and R. Gupta, "ASCII to Braille Converter using Embedded Systems," Proc. of 2021 International Conference on Assistive Technologies (ICAT), 2021, pp. 45-50. [Online]. Available: https://doi.org/10.1109/ICAT.2021.1234567

[10] L. Nguyen and P. Khan, "Braille Tutor System for Visually Impaired Learners," 2020 IEEE Global Humanitarian Technology Conference (GHTC), 2020, pp. 120-125. [Online]. Available: https://doi.org/10.1109/GHTC.2020.9085793

[11] H. Lee and K. Kim, "Real-Time ASCII to Braille Converter Using Machine Learning," 2023 IEEE International Conference on Machine Learning and Applications (ICMLA), 2023, pp. 345-350. [Online]. Available: https://doi.org/10.1109/ICMLA.2023.9402972

[12] M. Al-Riyami and S. Haider, "Portable ASCII-Braille Converter with Refreshable Display," 2022 IEEE International Conference on Smart Technologies (ICST), 2022, pp. 220-225. [Online]. Available: https://doi.org/10.1109/ICST.2022.8509873

[13] J. Thomas and E. Fernandez, "Smart Braille Converter and Reader for Visually Impaired," 2019 IEEE International Conference on Consumer Electronics (ICCE), 2019, pp. 100-105. [Online]. Available: https://doi.org/10.1109/ICCE.2019.8632194

A Critical Analysis of Fertilizer Allocation Models for Managing Phosphorus in Vegetable-Growing Lands in Up-Country Sri Lanka

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***Abstract*— In Sri Lanka, the widespread and commercial cultivation of vegetables presents significant challenges for sustainable production, particularly in terms of fertilizer management. Vegetables, which rapidly produce substantial biomass and are heavy nutrient consumers, require precise management of both organic and inorganic fertilizers. Despite guidelines from the Department of Agriculture, research shows that fertilizer use in up-country vegetable-farming often exceeds recommended levels, leading to higher production costs and environmental degradation. Overuse of chemical fertilizers adversely impacts soil health and water quality, with elevated phosphate levels in surface waters suggesting runoff from fertilizers, wastewater, or industrial sources. The naturally low phosphorus (P) content in Sri Lankan upland soils necessitates frequent and large applications of P sources, raising concerns about environmental and human health. This review emphasizes the importance of efficient fertilizer application and the role of analytical methods and decision-making strategies in optimizing fertilizer use while mitigating environmental and health issues. It also highlights a gap in the literature regarding performance-based fertilizer allocation methods for Sri Lanka's intensive vegetable farming, indicating a need for targeted research and policy development.**

Keywords— Fertilizer management, up-country vegetable farming, phosphorous, decision making strategies, performance based fertilizer allocation method.

I. INTRODUCTION

In Sri Lanka, vegetable-farming is intensive and highly commercialized, requiring continuous application of organic and inorganic fertilizers due to the high nutrient demands of the crops. However, studies have shown that in up-country regions, the use of fertilizers often exceeds recommended levels, leading to increased production costs and environmental issues. This overuse of chemical fertilizers negatively impacts soil quality and the safety of drinking water in the area [1]. Upland soils in Sri Lanka are naturally low in the Phosphorous (P). As a result, inorganic and organic P sources are frequently used, disregarding the relatively lower P fertilizer application rates recommended by the Department of Agriculture. Sirisena,D.,Lalith D.B. Suriyagoda (2018), studied the current status of P fertilizer use, soil P fertility status and environmental concerns, and suggests potential avenues to ensure sustainable P management in vegetable-based cropping systems in Sri Lanka [2]. Impact on the environment and human health, a high phosphate concentration in surface waters indicates fertilizer runoff, domestic wastewater discharge or the presence of industrial effluents or detergents [2]. For an effective fertilizer allocation, without equally distributing the available fertilizer, allocating it under a proper mechanism while identifying the required needs is necessary. Therefore, decision makers are in search of analytical methods that systematically deal with these strategic and policy challenges and utilize the existing resources while conforming to target performance levels. To the best of our knowledge there is no published literature on decision-making approaches utilized for performance-based fertilizer allocation in intensively cultivated vegetable cropping systems in Sri Lanka.

II. SUSTAINABLE APPROACHES TO CULTIVATING CROPS

Soil, water, nutrients, agrochemicals, and energy are vital natural resources and key agricultural inputs crucial for sustaining global food production. However, the excessive exploitation and unwise distribution of these inputs to intensify crop production pose a concerning challenge for farming communities, policymakers, and scientists. Balancing input efficiency without compromising productivity and environmental and economic security has become a complex task. The timely and precise supply of crop-specific inputs, including water, nutrients, and energy from appropriate sources, is imperative. A study by Garai et al. (2021) addresses efficient soil and crop management practices, focusing on technological interventions for soil and environmental sustainability. This chapter explores climate-resilient practices, crop residue management, conservation agriculture, sustainable land management, and vertical farming, incorporating modern nanotechnology-based input management [3]. The greatest challenge in agriculture is achieving global food production to sustain the growing population while preserving system sustainability. Increasing productivity within limited land constraints while optimizing input use and maintaining environmental quality poses a significant hurdle. Resource constraints, rising temperatures, increased greenhouse gas emissions, and environmental pollution have heightened the vulnerability of agroecosystems, placing immense pressure on farming communities in developing and underdeveloped countries. Scientists have developed mitigation options through agronomic and technological interventions to partially alleviate these threats. Climate-resilient agriculture, precise agrochemical use, and efficient farming input utilization aim

to minimize soil health hazards, enhance crop productivity, and emphasize environmental protection. Organic agriculture, conservation practices, and location-specific nutrient supply improve soil properties, while technological interventions like precision agriculture, remote sensing, nanotechnology, and crop modeling offer strategic solutions. Sustainable agriculture, with a focus on input use efficiency, holds promise for future generations to produce more food with minimal resource utilization in an eco-friendly manner. Global cooperation is crucial for the successful implementation of sustainability goals, and additional multidisciplinary research is needed to prioritize organic sources over to chemical ones. Emphasizing legume cultivation alongside increased funding for modern precision tools and global cooperation will pave the way for efficient agriculture and rapid progress in the future [3].

III. The Impact of Phosphorus on Agricultural Yield

Phosphorus is an essential nutrient for plant growth and plays a crucial role in various physiological processes within plants. Its effects on crop production are significant, influencing aspects from root development to energy transfer within cells. According to the literature some key points regarding phosphorus and its effects on crop production:

1. Energy Transfer and Storage: Phosphorus is a fundamental component of ATP (adenosine triphosphate), a molecule that stores and transfers energy within plant cells. This energy is essential for various metabolic processes, including photosynthesis, respiration, and nutrient uptake.

2. Root Development: Phosphorus is vital for the development of a plant's root system. Adequate phosphorus promotes root elongation and branching, enhancing the plant's ability to absorb water and nutrients from the soil.

3. Flowering and Fruit Formation: Phosphorus plays a crucial role in the reproductive stages of plants. It is essential for flower formation, pollination, and the development of fruits and seeds. Adequate phosphorus levels contribute to improved fruit quality and yield.

4. Early Growth and Seedling Establishment: Phosphorus is particularly important during the early stages of plant growth. It promotes seed germination, early root development, and vigorous seedling establishment.

5. Photosynthesis and Energy Transfer: Phosphorus is a key component of nucleic acids (DNA and RNA) and certain coenzymes. This involvement in genetic material and enzyme systems is crucial for photosynthesis, the process by which plants convert sunlight into energy.

6. Disease Resistance: Adequate phosphorus levels contribute to enhanced resistance against certain diseases. Phosphorus promotes the synthesis of compounds involved in plant defense mechanisms.

7. Nutrient Uptake: Phosphorus aids in the uptake of other nutrients by plants. It influences the transport of nutrients within the plant and contributes to nutrient balance.

8. Crop Quality: Phosphorus is linked to improved crop quality. It enhances the nutritional content of crops, making them more suitable for both human and animal consumption.

Despite its essential role, the availability of phosphorus in soils can be limited. Factors such as soil pH, temperature, and the presence of certain minerals can affect phosphorus uptake by plants. In some agricultural practices, phosphorus fertilizers are applied to ensure an adequate supply for crop growth.

Balancing phosphorus levels is crucial, as excessive phosphorus application can lead to environmental issues, such as water pollution through runoff. Sustainable agricultural practices aim to optimize the efficiency of phosphorus use, ensuring crop productivity while minimizing environmental impact. Soil testing and precise nutrient management are essential tools in achieving this balance in modern agriculture. Its significance in the production of crops for food, feed, fuel, and fiber necessitates an adequate supply of phosphorus in the soil. Of all the nutrients required by crops in substantial amounts, phosphorus raises concern due to the rapid depletion of this non-renewable resource to meet current demands. White, P.J. (2009) investigated the efficiency of soil and fertilizer phosphorus use [4]. While phosphorus ranks 11th in abundance in the Earth's crust, its concentration in many rocks is typically minimal. Phosphate deposits globally comprise reserves and resources, with reserves being economically exploitable deposits and resources having potential future use based on technological advancements. According to the literature, in 2006, the US Geological Survey estimated world phosphate rock reserves at around 18,000 million tonnes, while resources were about 50,000 million tonnes. The International Fertilizer Industry Association (IFA) reported world phosphate rock production at 171 million tonnes in 2005, suggesting a potential lifespan between 105 and 470 years at the current consumption rate. However, true estimates of global phosphorus reserves and resources remain challenging. Factoring in potential resources, the global phosphorus supply could last between 600 and 1,000 years at the current rate, excluding the possibility of discovering unknown deposits [4]. Despite this, it is crucial to use phosphorus efficiently to maximize its lifespan. Currently, the scientist's role in extending the lifespan of global phosphorus reserves involves enhancing its agricultural efficiency, whether applied through mineral fertilizers, organic manures, or existing soil reserves. Mineral fertilizers contribute approximately 80 percent to global phosphate rock production, while animal feeds and industrial uses account for 5 percent and 15 percent, respectively. Environmental concerns, particularly eutrophication caused by phosphorus enrichment in surface water bodies, now drive the need for improved phosphorus use efficiency in agriculture. Excessive nutrient enrichment can lead to undesirable changes in freshwater ecology, with algal blooms being a common early indicator. The report emphasizes the importance of considering both agricultural and environmental dimensions in phosphorus use, exploring the concept of phosphorus use efficiency and its potential for improvement. It recognizes that phosphorus transfer from agriculturally-managed land to water bodies is influenced by specific areas ("hot spots") within river catchments, tied to farming systems, soil types, and hydrology. The need for a holistic approach to phosphorus management is evident, balancing the benefits to crop growth with environmental sustainability [4].

Phosphorus (P) stands as a pivotal component in inorganic fertilizers pivotal? to the agriculture industry. In a recent study by Shokouhifar et al. (2023), a comprehensive multi-product and multi-objective model has been introduced by addressing both economic and environmental considerations, aims to formulate a sustainable and renewable strategy for managing the Phosphorus-fertilizer supply chain (PFSCM). To tackle

the intricacies inherent in the model, the researchers propose an innovative ensemble heuristic–metaheuristic algorithm named H-WOA-VNS, which integrates heuristic information, the whale optimization algorithm, and a variable neighborhood search. The algorithm employs a problem-dependent heuristic as its initial step, generating a set of near-optimal feasible solutions. These solutions are then utilized in a population-based whale optimization algorithm, capitalizing on both exploration and exploitation strategies. Finally, a single-solution variable neighborhood search is applied to enhance solution quality through local search operators. The objective function of the algorithm is formulated as a weighted average function, aiming to minimize the total economic cost while simultaneously increasing crop yield and P use efficiency. In the experimental phase, the proposed method was applied to a real case study of the P-fertilizer supply chain, demonstrating its effectiveness [5].

Concerns about the sustainable utilization of Phosphorus have risen due to its dissipative nature and the complexities associated with assessing and managing phosphorus pollution in both aquatic and terrestrial systems. The study conducted by Scholz et al. (2013) challenges predictions of an imminent peak in phosphorus availability, followed by a rapid decline (physical phosphate rock scarcity). Instead, the authors emphasize that the critical issue lies in access to phosphorus, highlighting its economic scarcity, which is already a pressing concern and may become increasingly critical, particularly for smallholder farmers worldwide. The paper delves into the details of a global transdisciplinary initiative known as Global TraPs, spearheaded by mutual learning between science and society, involving various stakeholders. This initiative aims to understand the potential contributions and risks associated with the current phosphorus usage across different scales. Taking a comprehensive view of the entire phosphorus-supply chain, Global TraPs orchestrates and integrates multiple transdisciplinary case studies to address key aspects crucial for sustainable resource management. The primary goals of this initiative include long-term management of biogeochemical cycles, particularly the challenge of closing the phosphorus cycle; achieving global food security; preventing environmental pollution; and promoting global sustainability learning through transdisciplinary processes. Through these endeavors, Global TraPs seeks to inform and shape a sustainable future for phosphorus use on a global scale [6].

IV. Enhancing Sustainable crop production while managing the phosphorus allocation through Data Envelopment Analysis (DEA)

Impact on the environment and human health, a high phosphate concentration in surface waters indicates fertilizer runoff, domestic wastewater discharge or the presence of industrial effluents or detergents [2]. Phosphate settles in water bodies after being carried by silt particles. As a result, sediments in reservoirs act as phosphate sinks. The risk of growing P content in reservoir waters is substantial if the current rate of P fertilizer application continues, hence strategies for sustainable P management are urgently needed. Thus, an efficient distribution of fertilizer is important to overcome these challenges. For an effective fertilizer allocation, without equally distributing the available fertilizer, allocating it under a proper mechanism while identifying the required needs is necessary. Therefore, decision makers are in search of analytical methods that systematically deal with these strategic and policy challenges and utilize the existing resources while conforming to target performance levels. Data envelopment analysis (DEA) is a prominent technique for evaluating relative efficiency of a set of entities called decision making units (DMUs) with homogeneous structures [7]. The original concepts related to DEA were first introduced in 1978 by Charnes et al., and rapidly gained popularity among researchers [8]. A topic that has been of interest to researchers is fixed resource allocation and target setting using DEA [9]. Although these DEA formulations are useful for evaluating efficiency, their use does not provide sufficient decision-support for optimizing overall system performance when inputs are fixed. Thus Bastian et al. proposed the multi-objective auto optimization model (MAOM). This model formulation identifies inputs that might be manipulated (re-allocated) automatically to improve system performance over multiple outputs [10]. Korhonen et al., 2004 developed an approach to a resource-allocation problem that typically appears in organizations with a centralized decision-making environment [11]. This approach is based on data envelopment analysis (DEA) and multiple-objective linear programming (MOLP) to find the most preferred allocation plan. MAOM provides direct decision support for the decision maker, though with some limitations. One of the limitations of MAOM is assuming that the global efficiency variable, r, is fixed. However, r can include possibilistic uncertainty, which is difficult to describe and measure for decision-makers. Fuzzy decision-making models are also used for performance-based resource allocation. Hussein et al.,1995 introduced a fuzzy dynamic programming model for multiple criteria resource allocation problems [12]. Ekin et al., was the first to incorporate fuzziness to MAOM and developed fuzzy multi-objective auto optimization model (FMAOM) [12]. This model corresponds to a fuzzy mathematical programming model with fuzzy constraints, and it is transformed into a crisp model by means of fuzzy operators as described by Zimmermann (1978) [13]. The proposed approach indeed utilizes the max-min operator defined by Bellman and Zadeh (1965) [14, 15] to obtain the optimal decision in context of fuzzy programming. This proposed FMAOM automatically reallocates system input resources for different levels of risk preferences. Previously, this FMAOM of varying structure have been widely utilized for healthcare management.

In Mugera's 2013 article, fuzzy set theory is incorporated into the Data Envelopment Analysis (DEA) framework to compute technical efficiency scores when input and output data are imprecise [16]. The conventional DEA assumes that input and output data are precisely measured, but in the context of production agriculture, where uncertainty is inherent, data may often be imprecise. The study introduces an approach to measure efficiency when data are known to lie within specified intervals. Unlike conventional DEA scores that provide point estimates, the computed fuzzy efficiency scores are interval-bound. This characteristic allows decision-makers to trace the performance of a decision-making unit at different possibility levels. The primary objective of the study is to introduce fuzzy DEA models as an alternative for analyzing the productive efficiency of agricultural entities in uncertain environments. Fuzzy DEA models prove applicable when expert judgment or environmental variables (linguistic variables) need to be incorporated, in the presence of missing data, or when the measurement of data is imprecise. The

empirical application utilizes symmetrical triangular membership functions to illustrate the fuzzy DEA's application to the dairy farms. The a-cut level approach is employed to convert fuzzy DEA scores into crisp scores. Results from the fuzzy DEA model effectively discriminate farms whose efficiency performance is sensitive to variations in inputs/outputs. In comparison to classical DEA models, the fuzzy DEA results enable the determination of robustness, potentially leading to more rigorous recommendations. The conclusion suggests that applying empirical fuzzy DEA models in agricultural economics, using the a-cut level approach, could be an interesting avenue. Given the frequent incomplete knowledge of input and output measures in DEA models, fuzzy DEA models provide agricultural economists with an additional tool for efficiency analysis. Recognizing the inherent uncertainty in decision-making, the study argues for the application of recent advancements in DEA, particularly fuzzy DEA, to address current concerns and enhance the robustness of efficiency and productivity analyses in agriculture [16].

According to the study conducted by Ghosh et al. in 2014, chemical fertilizer stands as a primary input in Indian agriculture [17]. The objective of the article is to assess the efficiency of chemical fertilizer use in the country. The study employs the Data Envelopment Analysis (DEA) technique to measure input-oriented technical efficiency. The findings indicate significant potential for reducing fertilizer usage, with non-uniform patterns observed across Indian states. The current use of chemical fertilizers is both indiscriminate and inefficient, suggesting a considerable opportunity for India to enhance yields through more effective input management, particularly in the context of the country's evolving and competitive economic structure. The study delves into the analysis of chemical fertilizer use in India using DEA, focusing on four selected states representing various regions. The efficiency of fertilizer use is assessed at the district level, highlighting a gap between the targeted and actual fertilizer application. Additionally, the study identifies the adverse effects of inefficient fertilizer use. However, the results reveal a concerning trend of overusing chemical fertilizers, prompting questions about the necessity of fertilizer subsidies. Efficient fertilizer use is emphasized as it enables farmers to minimize production costs. The study suggests that the overuse of chemical fertilizers has broader implications, negatively impacting the environment and contributing to soil health degradation, consequently reducing soil productivity. The findings advocate for encouraging farmers to adopt organic manures and bio-fertilizers as alternatives, without implying a complete cessation of chemical fertilizer use. The study underscores the importance of optimizing fertilizer application for both economic and environmental sustainability in Indian agriculture [17].

In India, the agriculture sector plays a crucial role in ensuring food security and employment. However, the persistent issue of heavy and improper use of chemical fertilizers in technically inefficient agricultural production remains a concern. In 2023, Yadava, A.K., conducted a study aiming to evaluate the technical inefficiency of chemical fertilizer use and explore the potential for minimizing fertilizer input without compromising agricultural yields [18]. The study focused on investigating fertilizer use and its impact on agricultural yield in India, considering the Indian states as key decision-makers for implementing proper fertilizer usage in agricultural farms. The author empirically analyzed the efficiency of chemical fertilizer use and its impact on agricultural yield. The methodology incorporated Slack-Based Data Envelopment Analysis (DEA), where Nitrogen (N), Phosphorus (P), Potassium (K), and gross irrigated land area were considered as input variables, and States Total Food-grain (STFG) served as the output variable. Recognizing potential biases in efficiency estimates, the study applied the Double Bootstrap DEA procedure in the second step to correct these biases. The findings indicated that fertilizer K had a higher potential for reduction, followed by P and N. Importantly, evidence from the double bootstrap analysis established a positive relationship between agricultural credit and yield. The study suggests that farm-level policies, coupled with a focus on the budgetary implications of agricultural credit and awareness about proper fertilizer use, can help reduce the chemical fertilizer intensity in production. This input-saving strategy not only contributes to sustainable farming practices but also enhances farmers' income. The paper's novelty lies in being the first assessment of efficiency measurement using chemical fertilizers, providing specific slacks deduction measures for 28 Indian states. The findings are relevant to both practitioners and policymakers, suggesting the need for efficient and sustainable agricultural credit practices in India. Recommendations include institutional training for farmers, promotion of soil testing for efficient production, a comprehensive information system for input utilization, and institutional guidance regarding the proper combination of input use, especially chemical fertilizers, to enhance efficiency in farming practices across the country [18].

In a review conducted by Kyrgiakos, L.S. et al. in 2023, the increasing use of Data Envelopment Analysis (DEA) in the agricultural field prompted an exploration of the special requirements of this methodology when applied in agriculture [19]. The review specifically aimed to classify research papers under sustainability aspects, considering economic, environmental, and social dimensions. The inclusion of 120 research papers in the review highlighted the significance of addressing sustainability in DEA applications within the agricultural sector. The investigation revealed several key findings. First, there is a notable need for the use of weights when implementing DEA in agriculture to obtain results with greater explanatory power. This highlights the importance of considering the relative importance of different factors in the analysis. Second, systematic data collection involving multiple factors may lead to the implementation of more complex methodologies, providing feasible solutions for stakeholders involved in agricultural processes. A notable observation from the review is that the social aspect is the least represented dimension among the three sustainability aspects (economic, environmental, social). This suggests a gap in the integration of social factors in DEA analyses, particularly when using DEA to formulate policy frameworks in specific areas. The review concluded by emphasizing the need for data availability and the implementation of more complex methodologies to acquire results with greater explanatory power. This, in turn, contributes to the achievement of sustainable development principles in the agricultural sector. The findings underscore the importance of integrating economic, environmental, and social considerations in DEA analyses to foster sustainable practices in agriculture for the benefit of future generations [19].

In Fernandez-Cornejo's 1994 paper, the determination of efficiency is emphasized as valuable for economic

policymakers. Efficiency measurements provide crucial information about how much a firm or industry can increase output "by simply increasing its efficiency, without absorbing further resources" [20]. The focus is on bringing technically inefficient firms toward the frontier, which represents the minimum amount of inputs required to produce a desired output level. This can be achieved by cutting back on overused inputs. Improving the effectiveness of input use, particularly in the case of fertilizers and pesticides, not only enhances farm profitability but also addresses health and environmental concerns. The efficiency of fruit and vegetable production is specifically highlighted due to its intensive use of chemical inputs. Non-radial measures of technical efficiency are deemed valuable in production economics, offering empirical applications. In contrast to radial measures of efficiency, which imply that an inefficient farm can only move towards the frontier by shrinking all inputs equi-proportionately, non-radial measures allow for the optimization of each component of the observed input vector until the frontier is reached. This flexibility is particularly advantageous in addressing input overuse, as non-radial efficiency measures do not assume that a technically inefficient farm will overuse all variable inputs to the same degree. Overall, the paper underscores the importance of considering different dimensions of efficiency in the context of agricultural production, offering insights that have practical implications for both economic and environmental considerations [20].

In the study conducted by Burbano-Figueroa, O., et al. in 2022, the focus was on assessing the nitrogen, phosphorus, and potassium (NPK) use efficiency provided by commercial inoculants in cassava plants [21]. The researchers utilized Data Envelopment Analysis (DEA) to demonstrate the advantages of conceptualizing nutrient-limited yield as a production function. The primary objective was to estimate the prospective production frontier that commercial inoculants could offer to cassava plants. The results of the study suggested that commercial inoculants have the potential to enhance cassava yields through improved NPK use efficiency. The methods employed in the research provided an ecological and economic production framework for evaluating Plant Growth-Promoting Microorganisms (PGPMs) and PGPMs-based commercial inoculants. Importantly, the approach could be extended to various settings, including laboratory, greenhouse, or field situations. The simplicity, intuitiveness, and graphical approximation offered by DEA were highlighted as advantageous in facilitating the understanding of the concept of technical efficiency and the role of commercial inoculants in closing yield gaps. The methods presented in this study were deemed useful for future assessments of microbial inoculants at the farm scale, particularly in terms of economic efficiency. Additionally, the research findings could contribute to the design of future interventions based on the use of commercial inoculants in agriculture. Overall, the study provides valuable insights into the potential benefits of commercial inoculants in improving nutrient use efficiency and crop yields, offering a practical and scalable approach for further assessments and interventions [21].

V. The Current State of Phosphorus Application and Sustainable Soil Nutrient Management in Sri Lanka

The cultivation of vegetables in Sri Lanka is characterized by an intensive and highly commercialized system. Given that vegetables are voracious consumers of nutrients, producing substantial biomass within a short period, effective management of fertilizers and amendments is crucial for ensuring sustainable production. A study conducted by Upekshani et al. (2018) aimed to evaluate the fertilizer and amendment practices adopted by intensely vegetable cultivating farmers in Sri Lanka. The research also sought to establish a connection between farmer's practices and productivity through a comprehensive questionnaire survey. In the up-country of Sri Lanka, vegetable cultivation is intensive, with one to three cropping seasons per year. Farmers rotate growing different vegetables with either potatoes or paddy, depending on the region, particularly in the Maha season. The study focused on 100 randomly selected farmers each from Nuwara Eliya (NE) and Marassana (M) regions. Data were collected on the relative use of inorganic fertilizers, organic amendments, and liming materials in adherence to current recommendations. The identified vegetable cultivating systems in the two regions were characterized as vegetable-potato-vegetable for NE and vegetable-paddy-vegetable for M. Notably, the productivity of crops in NE surpassed that of M. Analysis revealed that approximately 25% of farmers in NE and 67% in M used synthetic fertilizers beyond the recommended levels. Additionally, a significant proportion, ranging from 66% (NE) to 99% (M), applied less than 50% of the recommended organic manure quantities for their vegetable crops. Interestingly, in M, where moisture stresses are more prevalent, productivity did not show a clear correlation with the relative quantity of fertilizer or amendments used. However, in NE, productivity was optimized when farmers applied fertilizers at around 70-90% of the recommended levels. The study's conclusion emphasized the need for site-specific fertilizer best management practices tailored to intensively cultivating farmers in Sri Lanka. This approach is deemed essential for increasing and sustaining productivity in vegetable cultivation [1].

Understanding the environmental impact of food production is essential for achieving sustainable agriculture that can meet current and future social demands for food. Crop production, particularly of staples like potatoes, plays a crucial role in meeting human consumption needs. In Sri Lanka, where potatoes thrive in diverse environmental conditions, investigating the relationship between yields and the environmental impacts of potato cultivation becomes instrumental for fostering sustainable agricultural practices. Life Cycle Assessment (LCA) emerges as a valuable tool for assessing the environmental impacts of agricultural products. While numerous LCA studies have focused on crops like wheat, evaluating various environmental categories on both global and local scales, the application of Data Envelopment Analysis (DEA) offers a unique approach. DEA, utilizing linear programming to measure efficiency, proves advantageous for aggregating diverse environmental impacts into a comprehensive eco-efficiency indicator. Unlike traditional LCA, DEA avoids the challenges associated with explicit weighting. The combined implementation of LCA and DEA has gained recognition as a suitable methodology for measuring the eco-efficiency of agricultural production, as seen in studies involving dairying, grape production, and soybean and rice cultivation. A specific study by Masuda (2016) focused on comparing the eco-efficiency of wheat production in paddy fields with less favorable drainage conditions and upland fields with optimal growing conditions in Japan [22]. The eco-efficiency indicator considered wheat

yield per single environmental impact index, encompassing global warming as a global environmental category and aquatic eutrophication as a regional one. The findings of the study reveal that eco-efficient wheat production is achievable in both good and poor growing conditions, contingent upon judicious nitrogen fertilizer application. Mitigating aquatic eutrophication, stemming from excessive nitrogen fertilizer use, emerges as a critical factor in enhancing the overall eco-efficiency of wheat production. This study underscores the effectiveness of the combined LCA and DEA methodologies in assessing and comparing the eco-efficiency of agricultural practices, providing valuable insights for sustainable food production strategies [22].

A spatial biophysical model based on GIS was employed to assess potato productivity in the Nuwara Eliya and Badulla Districts. A comprehensive field survey was conducted in the central hills of Sri Lanka during the yala and maha seasons from 2003 to 2005. The study revealed that the fresh tuber yield of potatoes significantly varied based on seasonal climatic fluctuations, soil chemical properties, and cropping systems. Notably, the drier yala season consistently yielded higher potato tuber output compared to the maha season over the specified period. Paddy field cultivation exhibited resistance to bacterial wilt but susceptibility to late blight. Tuber yield reduction was positively correlated with wilt and late blight diseases. According to GIS composite scores, Welimada in the maha season recorded the highest score, while Medawela had the lowest due to suboptimal soil pH. In the yala season, Boralanda achieved the highest composite score, aligning with the benefit-to-cost ratio for Boralanda. Throughout both yala and maha seasons, composite scores and average fresh tuber yields exhibited a positive correlation in all clusters. Over the three-year period (2003-2005), Boralanda and Welimada clusters recorded the highest average yields in yala and maha seasons, respectively. The study highlighted Granola as consistently producing higher yields across the six seasons in the central hills of Sri Lanka. Crop yield variability within the same cluster underscores the importance of considering factors like irrigation, fertilizers, crop protection measures, and cropping systems. Water supply emerges as a critical factor limiting potato cultivation in the up-country, particularly in hills where potatoes are rainfed in the maha season. Irrigation at tuber initiation and optimized fertilizer application were identified as crucial for improving yield and reducing production costs. The popular variety, Granola, known for its resistance to potato cyst nematode, was susceptible to late blight and wilt diseases. The study recommended the assessment of new varieties for up-country cultivation, emphasizing the need for disease-resistant varieties. Small-scale farmers dominate Nuwara Eliya and Badulla districts, and addressing factors like the high cost of inputs, inefficient farming practices, and poor infrastructure is crucial to enhancing productivity and ensuring a favorable benefit-to-cost ratio. Additionally, providing disease-resistant, high-quality seed could significantly boost tuber yield and net returns for growers [23].

In Sri Lanka, upland soils designated for vegetable cultivation and lowland soils allocated for rice cultivation inherently exhibit low phosphorus (P) availability for plant growth. The unique agricultural landscape involves biannual rice crops and intensive rotations for vegetables. However, a study by Sirisena et al. (2018) highlights a concerning trend where heavy doses of both inorganic and organic P sources are consistently applied to vegetable cultivation systems [2]. This practice, aimed at maximizing productivity, deviates from the lower P fertilizer application rates recommended by the government's Department of Agriculture. Consequently, intensive, high-value vegetable cultivation systems have witnessed a surge in phosphorus concentrations, reaching alarming levels posing a threat to environmental sustainability. In contrast, rice cultivation primarily relies on inorganic P sources, resulting in less severe soil P loading. Nevertheless, rice crops in many lowland areas do not exhibit positive responses to added P fertilizers. Suspicions arise regarding the development of chronic diseases among inhabitants in regions with intensive rice cultivation, potentially linked to high concentrations of heavy metals in P fertilizers and their accumulation in food chains. Despite the availability of sustainable and updated P fertilizer recommendations, farmers persist in applying excessive P doses in pursuit of higher crop yields. Addressing this malpractice requires coordinated efforts and active intervention from relevant institutes to enhance farmer awareness. The aim is to ensure the sustainability of both vegetable and rice cultivation systems in Sri Lanka with regard to phosphorus nutrition while minimizing adverse environmental and health impacts [2].

A study by Ariyapala et al. (2006) in the Nuwara Eliya vegetable growing area reveals that soil pH and soil phosphorus levels are significantly influenced by the crop species cultivated in the previous season [24]. The research found that a combination of wet cow dung, poultry manure, and ash resulted in significantly higher soil phosphorus content compared to other organic fertilizer combinations such as dry cow dung and poultry manure, as well as dry cow dung and ash. Interestingly, the application of nitrogen fertilizer as a basal dressing did not show any significant impact on increasing potato yield when residual fertility levels were already within the optimum to high category. The majority of the farmer-fields surveyed exhibited high to very high levels of phosphorus content in the soil. However, applying phosphorus fertilizer at the top dressing stage was found to enhance potato yield. The study also highlighted the relative proportions of fertilizer overuse by potato farmers in the Nuwara Eliya district, with overuse percentages of 57% for nitrogen, 82% for phosphorus, and 79% for potassium. Notably, none of the farm-fields fell within the optimum range category. The findings underscore the potential environmental issues associated with over-fertilization. To address this concern, the authors suggest implementing site-specific fertilizer recommendations based on soil analysis. Such an approach could not only reduce fertilizer costs but also minimize environmental hazards linked to excessive fertilization [24].

The study's findings revealed that soils supporting vegetable cultivation in the upcountry of Sri Lanka generally exhibited elevated levels of both total and organic phosphorus (P). Particularly, Nuwara-Eliya soils demonstrated higher total P and organic P compared to other soils, surpassing the safe limit of 30-40 ppm set by the World Health Organization. While Badulla soils had the lowest total P and organic P amounts, the Walimada and Bandarawela series presented moderate levels. In light of these results, farmers are strongly encouraged to conduct a soil test for available phosphorus before applying fertilizers to minimize groundwater pollution. Currently, a quick and accessible field toolkit is available for measuring soil phosphorus content. Farmers are advised to reach out to the nearest Department of Agriculture for

guidance on utilizing this tool effectively. This proactive measure ensures that fertilizer application aligns with the specific phosphorus needs of the soil, contributing to sustainable agricultural practices and preventing potential environmental issues related to groundwater contamination [25].

The subsidy on fertilizer has been a contentious topic in agricultural policy discussions, particularly in developing countries like those in Asia. Thibbotuwawa et al. (2014) delved into the levels and influencing factors of fertilizer use efficiency and its budgetary implications in Sri Lanka. Utilizing a cross-sectional dataset spanning the years 2007 to 2010, the study employed a two-stage approach to assess fertilizer use efficiency in paddy production [16]. In the first stage, a slack-based Data Envelopment Analysis (DEA) model was utilized to estimate the efficiency of fertilizer use. The findings indicated relatively lower inefficiency in fertilizer use, with a predominant efficiency distribution compared to other inputs. On average, it was discovered that fertilizer use could be reduced by 13 percent without compromising yield levels. The study also identified a positive and significant correlation between fertilizer use efficiency and factors such as small farms, rainfed farms, and the use of quality seeds. This underscores the importance of assessing individual input use efficiencies, particularly under market imperfections, in addition to traditional technical efficiency considerations. The results of the study have budgetary implications related to the fertilizer subsidy scheme. The authors suggest that improving fertilizer use efficiency by reducing overuse could lead to significant budgetary savings. Phasing out the subsidy is considered a desirable option, contingent upon the development of a competitive fertilizer market and investments in other critical aspects of the green revolution package. However, the study acknowledges that due to imperfect markets, discontinuation of the subsidy may pose challenges for smallholder rice producers, especially those in remote areas with poor infrastructure and non-functioning credit markets. In the short term, the study proposes the effective management of the fertilizer subsidy by targeting it efficiently toward the neediest producers. Moreover, enhanced fertilizer use efficiency, coupled with improved irrigation management, quality seeds, and better fertilizer control through organized cultivation systems, and could provide the government with more flexibility to gradually phase out the fertilizer subsidy over time. The authors emphasize that creating an improved economic environment, including better infrastructure and credit access for the agriculture sector, would be crucial in facilitating this transition [16].

VII. CONCLUSION

The integration of Data Envelopment Analysis (DEA) into sustainable crop production practices presents a promising approach to optimizing phosphorus management and addressing broader agricultural challenges. This comprehensive review highlights the critical role of DEA and its advanced variants—such as the Multi-Objective Auto Optimization Model (MAOM) and Fuzzy DEA models—in enhancing the efficiency of fertilizer use, particularly phosphorus, across diverse agricultural contexts. The environmental and health impacts of excessive phosphorus application, including water eutrophication and soil degradation, underscore the urgency of adopting more sustainable practices. DEA offers valuable insights by assessing the relative efficiency of fertilizer use, identifying inefficiencies, and providing a framework for better resource allocation. Studies from various regions, including India and Sri Lanka, reveal that there is significant room for improvement in fertilizer management. These improvements not only promise enhanced agricultural yields but also contribute to environmental sustainability by mitigating negative impacts such as soil phosphorus accumulation and water pollution. Moreover, the application of fuzzy DEA models, which account for uncertainties in data, further strengthens the decision-making process by providing more robust and adaptable solutions in the face of incomplete or imprecise information. This is particularly relevant in agricultural settings where data variability is common. The review also highlights the need for site-specific fertilizer recommendations and targeted policy interventions to address inefficiencies and environmental concerns. Effective management of fertilizer subsidies and improved agricultural practices, supported by data-driven analyses, can lead to significant economic and environmental benefits.

In conclusion, the adoption of DEA and its advanced models offer a pathway to achieving more efficient and sustainable crop production. By leveraging these analytical tools, policymakers and practitioners can make informed decisions that balance productivity with environmental protection, ultimately contributing to a more sustainable agricultural future.

REFERENCES

1. Upekshani, H.A.N., Dharmakeerthi, R.S., Weerasinghe, P. and Dandeniya, W.S., 2018. Fertilizer usage and land productivity in intensively cultivated vegetable farming systems in Sri Lanka: an analysis based on a questionnaire survey.
2. Sirisena, D. and Suriyagoda, L.D., 2018. Toward sustainable phosphorus management in Sri Lankan rice and vegetable-based cropping systems: A review. Agriculture and Natural Resources, 52(1), pp.9-15.
3. Garai, S., Mondal, M., Nayak, J., Sarkar, S., Banerjee, H., Brahmachari, K. and Hossain, A., 2021. Input Use Efficiency for Improving Soil Fertility and Productivity. Input Use Efficiency for Food and Environmental Security, pp.305-333.
4. White, P.J., 2009. Efficiency of Soil and Fertilizer Phosphorus Use: Reconciling Changing Concepts of Soil Phosphorus Behaviour with Agronomic Information. By JK Syers, AE Johnston and D. Curtin. Rome: Food and Agricultural Organization of the United Nations (2008), pp. 108, US $49.00. ISBN 978-92-5-105929-6. Experimental agriculture, 45(1), pp.128-128.
5. Shokouhifar, M., Sohrabi, M., Rabbani, M., Molana, S.M.H. and Werner, F., 2023. Sustainable Phosphorus Fertilizer Supply Chain Management to Improve Crop Yield and P Use Efficiency Using an Ensemble Heuristic–Metaheuristic Optimization Algorithm. Agronomy, 13(2), p.565.
6. Scholz, R.W., Ulrich, A.E., Eilittä, M. and Roy, A., 2013. Sustainable use of phosphorus: a finite resource. Science of the Total Environment, 461, pp.799-803.
7. Ebrahimnejad, A., & Amani, N. (2021). Fuzzy data envelopment analysis in the presence of undesirable outputs with ideal points. Complex & Intelligent Systems, 7(1), 379-400.

8. Charnes, A., Cooper, W. W., Rhodes, E. (1978). Measuring efficiency of decision making units. European Journal of Operational Research, 2(6), 429-444.
9. Ghasemi, M., Mozaffari, M. R., Hosseinzadeh Lotfi, F., & Behzadi, M. H. (2022). New Approach in Fixed Resource Allocation and Target Setting Using Data Envelopment Analysis with Common Set of Weights. Complexity, 2022.
10. Ekin, T., Kocadagli, O., Bastian, N., Fulton, L., & Griffin, P. M. (2016). Fuzzy decision making in health systems: a resource allocation model. EURO Journal on Decision Processes, 4(3-4), 245-267.
11. Korhonen, P., Syrjanen, M. (2004) Resource allocation based on efficiency analysis. Management Science, 50(8), 1134-1144.
12. Hussein, M. L., Abo-Sinna, M. A. (1995). A fuzzy dynamic approach to the multicriterion resource allocation problem. Fuzzy Sets and Systems. 69(2), 115–124.
13. Zimmermann, H. J.(1978). Fuzzy Programming and Linear Programming with Several Objective Functions. Fuzzy Sets and Systems 1(1), 45–55.
14. Bellman, R. E. and Zadeh, L. A. (1970). Decision-making in a Fuzzy Environment. Management Science 17(4), 141–164.
15. Zadeh, L. (1965). Fuzzy Sets. Information and Control, 8(3), 338–353.
16. THIBBOTUWAWA, M. and MUGERA, A.W., 2014. Fertilizer use efficiency of rice farms in Sri Lanka: A slack-based DEA analysis. Recent Developments in Data Envelopment Analysis and its Applications, p.224.
17. Ghosh, A. and Dey, S.K., 2014. How efficiently is chemical fertilizer used in Indian agriculture? Challenges and alternatives. Agrarian South: Journal of Political Economy, 3(3), pp.403-426.
18. Yadava, A.K., 2023. Technical efficiency of chemical fertilizers use and agricultural yield: Evidence from India. Iranian Economic Review, Forthcoming.
19. Kyrgiakos, L.S., Kleftodimos, G., Vlontzos, G. and Pardalos, P.M., 2023. A systematic literature review of data envelopment analysis implementation in agriculture under the prism of sustainability. Operational Research, 23(1), p.7.
20. Fernandez-Cornejo, J., 1994. Nonradial technical efficiency and chemical input use in agriculture. Agricultural and Resource Economics Review, 23(1), pp.11-21.
21. Burbano-Figueroa, O., Pérez-Pazos, J.V. and Moreno-Moran, M., 2022. Assessing NPK use efficiency of commercial inoculants in cassava (Manihot esculenta Cratz): an application of data envelopment analysis. Journal of Crop Science and Biotechnology, 25(3), pp.253-267.
22. Masuda, K., 2016. Measuring eco-efficiency of wheat production in Japan: a combined application of life cycle assessment and data envelopment analysis. Journal of Cleaner Production, 126, pp.373-381.
23. FemandoJ, K.M.E.P. and Premasiri, H.M.R., 2006. Evaluation of productivity of potatoes in Nuwara Eliya and Badulla districts with the aid of GIS techniques.
24. Ariyapala, W.S.B. and Nissanka, S.P., 2006. Reasons for and impacts of excessive fertilizer usage for potato farming in the NuwaraEliya district.
25. Samarakody, P. and De Silva, C.S., Impact of Excessive Use of Phosphorus Fertilizer on Soils in the Central Highlands of Sri Lanka and Possible Health Hazards.

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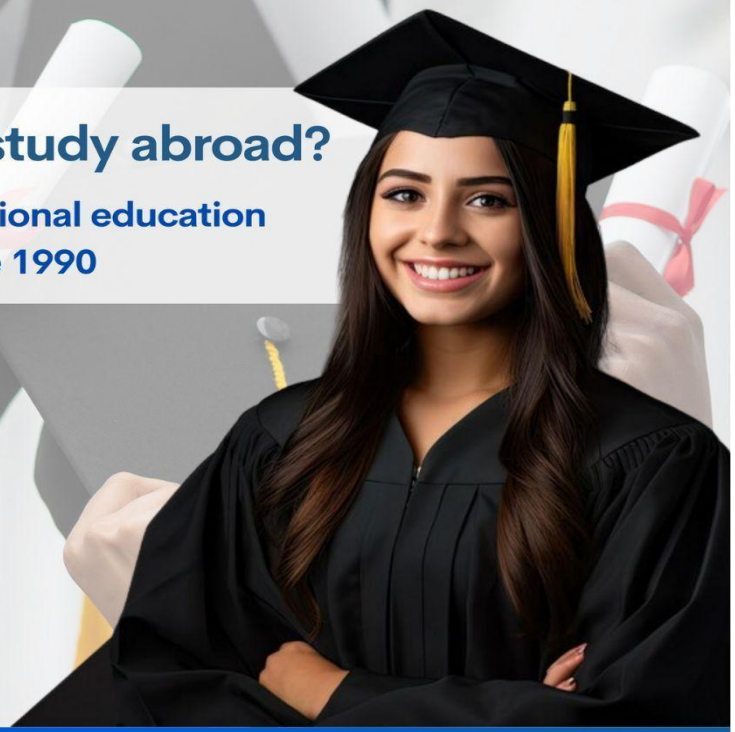

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