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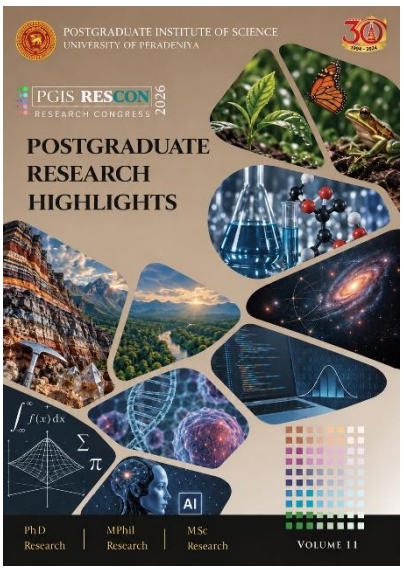
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MESSAGE FROM THE DIRECTOR



It is with great pleasure and pride that I present PGIS Postgraduate Research Highlights 2026, a publication that showcases the growing strength, diversity, quality, and impact of postgraduate research undertaken at the Postgraduate Institute of Science (PGIS), University of Peradeniya.

This volume brings together 35 research highlights representing a broad spectrum of scientific disciplines and research themes. Notably, the collection includes contributions from four PhD researchers and 17 MPhil researchers, reflecting the significant contribution of PGIS postgraduate programmes to the advancement of scientific knowledge, research capacity, and innovation. The research featured spans chemical and biological sciences, earth sciences, mathematics, statistics, computer science, and related fields, while addressing challenges of both national and international relevance.

A particularly noteworthy strength of this collection is the close connection between fundamental scientific inquiry and real-world applications. The research highlights address a diverse range of issues, including sustainable food resources, environmental remediation, climate and disaster-related processes, natural products, geological evolution, health-related challenges, mathematical modelling, and emerging technologies. Several studies demonstrate how Sri Lanka's natural resources, unique environments, and societal challenges can provide valuable platforms for generating scientific knowledge of broader international relevance.

The scholarly outcomes arising from these research activities are equally encouraging. Several studies presented in this volume have progressed beyond postgraduate research theses to peer reviewed journal publications and presentations at national and international conferences. These achievements provide tangible evidence of the vibrant research culture, academic rigour, and scholarly productivity fostered within PGIS.

This publication also highlights the multidisciplinary and collaborative nature of postgraduate research at PGIS. Meaningful research outcomes increasingly depend on collaboration among postgraduate researchers, supervisors, academic departments, research institutions, industry, and other external partners. Such partnerships are essential for addressing complex scientific and societal challenges and for translating research findings into innovative and sustainable solutions.

I extend my sincere appreciation to all postgraduate researchers and their supervisors for their scholarly rigour, creativity, dedication, and perseverance. I also acknowledge the Boards of Study and academic staff of PGIS for their continued guidance and support in nurturing the next generation of researchers.

I wish to place on record my sincere appreciation to Dr. Susanthi Jayasinghe, Editor-in Chief/PGIS Research Highlights Committee 2026 for their dedication, careful editorial work, and outstanding efforts in compiling and presenting the diverse research achievements featured in this publication.

I also gratefully acknowledge the Chairperson and Organizing Committee of RESCON 2026, together with the technical and administrative staff, collaborating institutions, research partners, and funding agencies whose contributions have supported the successful advancement and dissemination of postgraduate research at PGIS.

The achievements presented in this volume are a reflection of a shared commitment to research excellence and the pursuit of knowledge. They demonstrate the intellectual curiosity, creativity, and determination of our postgraduate researchers and the commitment of the wider PGIS community to advancing science for the benefit of society.

As PGIS moves forward, we remain committed to strengthening research excellence, fostering interdisciplinary collaboration, promoting innovation, and generating research outcomes with tangible national and global impact. I trust that *PGIS Postgraduate Research Highlights 2026* will serve not only as a record of our research achievements but also as a source of inspiration for further inquiry, collaboration, innovation, and scholarly excellence.

I warmly congratulate all researchers whose work is featured in this publication and wish them continued success in their academic and research endeavours.

Prof. Nanda Balasooriya
Director/ Postgraduate Institute of Science
University of Peradeniya

MESSAGE FROM THE CHAIRPERSON RESCON 2026



I am happy to present the PGIS Research Highlights 2026, published as part of the Sri Lanka's Premier Science Conference RESCON 2026: A Celebration of Postgraduate Research Excellence.

This volume showcases the most significant research achievements of graduate students who completed their PhD, MPhil, and MSc Degrees in 2025. Bringing this collection together was made possible through the commitment, expertise, and teamwork of the Research Highlights Committee of RESCON 2026, headed by Dr. Susanthi Jayasinghe, whose persistent dedication turned this vision into reality.

To every postgraduate of the 2025 cohort and their supervisors, I offer my deepest gratitude. Your exceptional work is the very foundation upon which this publication stands. Each of whom has contributed meaningfully to the dynamic research culture of the PGIS. More than a simple record of academic achievement, this publication opens a door to the remarkable breadth and depth of research conducted at PGIS with an open invitation to collaborate. Readers who wish to delve deeper into any of these topics are encouraged to reach out directly to the authors or their supervisors, creating opportunities for new academic and industrial partnerships.

While thanking the whole committee, Director-PGIS and the staff, I wish all the best for everyone who took part in compiling this volume as well as all contributors!

Prof. Sanjeewa P.K. Malaviarachchi
Chairperson, RESCON 2026
Postgraduate Institute of Science
University of Peradeniya

MESSAGE FROM THE EDITOR-IN-CHIEF



It gives me immense pleasure and pride to present *PGIS Research Highlights 2026*, a compilation of research works carried out by the graduates of 2025 of the Postgraduate Institute of Science (PGIS), University of Peradeniya. This volume brings together 35 research highlights representing the scholarly achievements of postgraduate researchers who successfully completed their PhD, MPhil, and MSc programmes. The articles featured herein provide a glimpse into the breadth and depth of research undertaken at PGIS in fulfilment of these postgraduate degrees.

Each research article represents the culmination of considerable intellectual effort, perseverance, and dedication. Behind these scholarly contributions are researchers who have explored challenging questions, applied diverse scientific approaches, and expanded the boundaries of knowledge in their respective fields. Collectively, these studies address contemporary scientific questions, generate new knowledge, and offer insights with potential relevance to academic advancement and the broader needs of society. This volume, therefore, serves not only as a collection of research findings but also as a celebration of the academic journeys and achievements of our graduates.

As the Editor-in-Chief of *PGIS Research Highlights 2026*, I extend my sincere congratulations to all the authors whose research is featured in this volume. I am deeply grateful to their research supervisors and mentors, whose guidance, expertise, and encouragement have been instrumental in shaping these successful research endeavours. My sincere gratitude also goes to the members of the editorial board of *PGIS Research Highlights* for their valuable contributions, careful review of the articles, and dedicated efforts in bringing this volume to fruition.

I would also like to express my sincere gratitude to the Director of the Postgraduate Institute of Science, Prof. Nanda Balasooriya, and the Chairperson of RESCON 2026, Prof. Sanjeewa P. K. Malaviarachchi, for their continued support and encouragement. My sincere appreciation also goes to the Organizing Committee of RESCON 2026 for their invaluable support in bringing this intellectual forum to completion.

May this volume serve as a lasting record of the research achievements of our graduates and inspire current and future postgraduate students to pursue knowledge with curiosity, creativity, and dedication. I hope that the research highlighted herein will encourage further collaboration, stimulate new ideas, and contribute to the advancement of science and its applications in Sri Lanka and beyond.

Dr. Susanthi Jayasinghe
Editor-in-Chief
PGIS Research Highlights 2026
Postgraduate Institute of Science
University of Peradeniya

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ISOLATION AND CHARACTERIZATION OF FORAGE ENSILING BACTERIA AND PRODUCTION OF SILAGE INOCULANT



K. Mithila Devindi *graduated in 2022 with a BSc (Hons) Degree in Animal Science and Fisheries from Faculty of Agriculture, University of Peradeniya, Sri Lanka. In 2025, she completed her MPhil Degree in Biochemistry and Molecular Biology at the Postgraduate Institute of Science (PGIS), University of Peradeniya, Sri Lanka. Devindi focused her research on the Isolation and Characterization of Forage Ensiling Bacteria and Production of Silage Inoculants. She continues research with a strong interest in Forage Science and Ruminant Nutrition.*

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Livestock production is a key component of Sri Lanka's agricultural economy, providing employment, food security, and nutritional support to rural communities. The dairy industry plays an increasingly important role in national nutrition and economy. The country produced approximately 506 million litres of milk in 2022, meeting only about 40% of total consumption. Thus, the country heavily depends on imported dairy products mostly as milk powder. Limited availability of good quality forage particularly during dry seasons is a major challenge for dairy cattle feeding in Sri Lanka.

Forage ensiling offers a practical and cost-effective strategy to conserve forage to ensure forage supply. During forage ensiling, under anaerobic conditions, epiphytic *Lactobacillus* species convert water-soluble carbohydrates (WSC) into lactic acid, reducing pH and inhibiting deterioration of forage by undesirable microorganisms such as *Clostridium*, yeasts, and molds. Further, rapid acidification is vital to suppress forage spoilage and proteolysis thereby preserve nutrients for ruminant feeding. *Lactiplantibacillus*, *Lacticaseibacillus, Pediococcus*, and *Leuconostoc* are formerly classified under the broad *Lactobacillus* group and are commonly found in high-quality silages. *Lactobacillus* plantarum belongs to *Lactiplantibacillus* while *Lactobacillus paracasei*, and *Lactobacillus rhamnosus* belongs to *Lacticaseibacillus*. They are the most widely used species in silage inoculants due to their strong acidification ability, homo- or hetero-fermentative metabolism, and tolerance to low pH.

The biodiversity conservation policy of the Government of Sri Lanka strictly regulates the importation of live microbial cultures, including silage inoculants, under the Animal Feed Act (1983). Additionally, commercial inoculants developed under temperate environments may not perform effectively under the country's warm, tropical, and humid conditions. Despite the proven benefits of microbial inoculation for enhancing silage quality, limited research has been conducted in Sri Lanka for the production of silage inoculants from locally available *Lactobacillus* species. The overarching objective of the present research study was to isolate, characterize, and evaluate indigenous lactic acid bacteria for the development of a tropical-adapted silage inoculant suitable for forage conservation under Sri Lankan conditions.

Methodology

Source of *Lactobacillus*:
Silage samples of maize (*Zea mays*), sorghum (*Sorghum bicolor*), and hybrid Napier (*Pennisetum crosses*) were collected from different regions of Sri Lanka (Central,

North Central, and Northern provinces). Approximately 250 g of each sample was sealed in sterile polyethylene bag, transported on ice, and stored at –4 °C until analysis.

Isolation and Characterization of *Lactobacillus*:
Lactic acid bacteria (LAB) were isolated using de Man, Rogosa, and Sharpe (MRS) agar medium. Ten grams of each silage sample were homogenized in sterile water, serially diluted, and plated on MRS agar. Typical LAB colonies were purified through successive streaking and maintained on MRS agar slants at 4 °C. Isolates were examined microscopically following Gram staining and tested for catalase activity to confirm genus-level identity. Ten pure cultures exhibiting Gram-positive and catalase-negative reactions were subjected to molecular characterization.

Genomic DNA was extracted using the Presto™ Mini gDNA Bacteria Kit (Geneaid Biotech, Taiwan). The 16S rRNA gene was amplified by polymerase chain reaction (PCR) using universal primers 27f and 1492r, and sequenced at Macrogen Inc., South Korea. Sequence alignment and species identification were performed using the National Center for Biotechnology Information Basic Local Alignment Search Tool (NCBI BLAST), while phylogenetic analysis was carried out with Geneious (MEGA) software. The sequences were deposited in GenBank under accession numbers PV938929–PV938938.

Determination of Acidification Potential of *Lactobacillus* Isolates:
Forage-extract (FE) media were prepared from dried and ground maize, sorghum, and *Brachiaria brizantha* forages (1:10 w/v). After autoclaving, 50 mL of each FE medium was separately inoculated with 1 mL of *Lactobacillus* isolates and incubated at 37 °C for 24 h. The reduction of pH was recorded at 1, 3, 5, 7, 9, and 24 h. The study was conducted in a complete Randomized design (CRD) with four replicates. Three isolates that exhibited superior acidification ability; *Lactobacillus plantarum* (LPL2), *Lactobacillus paracasei* (LPC1), and *Lactobacillus rhamnosus* (LRA1) were selected.

Determination of Ensiling Potential of Single and Multiple *Lactobacillus* Inoculum:
The selected *Lactobacillus* cultures (LPL2, LPC1, LRA1) isolates were cultured in MRS broth at 37 °C for 24 h, harvested by centrifugation (8,000 rpm, 20 minutes, 4 °C), and resuspended in 10% (w/v) non-fat milk. Aliquots (1 mL) of the suspensions were dispensed into freeze-drying vials and lyophilized using a freeze-drier to prepare *Lactobacillus* inoculants. The viability of the freeze-dried inoculants was assessed.

Hybrid fodder maize (R4 stage) was harvested and chopped using a commercial forage harvester. The experiment consisted six *Lactobacillus* inoculant treatments (LPC1, LPL2, LRA1, LPC1 + LRA1, LPL2 + LRA1, and LPC1 + LRA1+ LPL2) and a control (uninoculated). Each inoculant was dissolved in 20 mL of deionized water and sprayed into chopped fodder maize at 10^6 CFU g^{-1} fresh forage. For the control, 20 mL of deionized water was sprayed onto fodder maize without any inoculant. Inoculated forages were packed tightly into 1 L airtight glass laboratory silos, sealed and stored at ambient temperature (25 - 30 °C). Four replicate silos per treatment were opened after 2 weeks and 6 weeks of ensiling.
Silage at the top 50 mm was discarded, and the rest was removed into a clean stainless-steel bowl. Silage samples characterized by a yellow-green color, a pleasant fruity or mildly vinegary odor, a non-sticky texture, and the absence of visible mold growth were considered acceptable for subsequent analyses. The silage was well-mixed and a representative sample from each was taken for the determination of the fermentation characteristics and nutritive value.

Results and Discussion

All isolates were Gram-positive, exhibited typical *Lactobacillus* colony morphology (circular or irregular shape, small or medium size, white to cream color, smooth surface, flat or slightly elevated, entire margin), were non-motile, and were negative for catalase activity.

The mean DNA concentration of the extracts was 19.42±1.89 ng/µL. DNA sequence analysis confirmed that the isolates were *Lactobacillus plantarum* (LPL1, LPL2, LPL3, LPL4, and LPL5, isolates), *Lactobacillus paracasei* (LPC1, LPC2, LPC3, and LPC4, isolate), and *Lactobacillus rhamnosus* (LRA1 isolate). A noticeable ($p<0.05$) pH reduction was evident in maize FE media due to inoculation with LPL2, LPC1, and LRA1 isolates. Similarly, LPL5, LPC2, and LRA1 isolates reduced ($p<0.05$) the pH of sorghum FE media. Except LPL2, none of the *Lactobacillus* isolates were able to reduce the pH of Brachiaria FE media below 4.0.

Fermentation characteristics of maize silage inoculated with *Lactobacillus* and ensiled for 6 weeks is shown in Table 1. Silage inoculated with *L. paracasei* (LPC1), alone or in combination with *L. rhamnosus* (LPC1+LRA1), exhibited the lowest pH values, indicating rapid and sustained acidification. The triple-species inoculant (LPC1 + LRA1 + LPL2) produced the highest ($p<0.05$) lactic acid concentration and lowest residual water-soluble carbohydrate content, suggesting synergistic microbial interactions and more exhaustive substrate utilization during fermentation. In contrast, uninoculated silage showed a relatively higher pH and greater residual sugars despite lactic acid accumulation, indicating less efficient fermentation likely dominated by epiphytic microorganisms. Ammonia-N concentrations remained low and did not differ significantly ($p>0.05$) among treatments, suggesting suppression of proteolysis.

Nutritional quality of maize silage inoculated with *Lactobacillus* and ensiled for 6 weeks is presented in

Table 2. Most inoculated silages, particularly those treated with *L. plantarum* (LPL2), showed slightly higher crude protein contents, indicating improved nitrogen preservation. Overall, inoculant selection influenced fermentation pathways and nutrient preservation. *Lactobacillus paracasei* (LPC1) promoted rapid pH stabilization, whereas the three-species consortium (LPC1 + LRA1 + LPL2) enhanced lactic acid production and carbohydrate utilization. Single-species inoculants provided a balance between fermentation efficiency and nutrient retention. These findings highlight the role of microbial interactions among *Lactobacillus* species achieved rapid pH reduction with efficient substrate utilization indicating its effectiveness in early silage stabilization. Single inoculants (*L. plantarum* and *L. rhamnosus*) provided effective fermentation while supporting better retention of digestible components. Selection of inoculants should therefore be strategically done based on the primary goal: whether it is maximum aerobic stability (*L. paracasei* + *L. plantarum* + *L. rhamnosus*), rapid initial stabilization (*L. paracasei*), or a balance of stability and nutrient retention with single species inoculant.

Table 1. Effect of *Lactobacillus* inoculum on the fermentation characteristics of maize silage at 6 weeks ensiling

Inoculum	pH value†	Lactic acid (%)†	Soluble carbohydrate (%)†	Ammonia – N (%)†
Control (without inoculum)	3.64 ± 0.03^{a}	8.17 ± 0.21^{abc}	1.68 ± 0.26^{ab}	0.05 ± 0.01^{a}
LPC1	3.52 ± 0.02^{b}	7.98 ± 0.12^{c}	1.12 ± 0.14^{cd}	0.05 ± 0.01^{a}
LPL2	3.62 ± 0.02^{a}	8.24 ± 0.12^{b}	1.41 ± 0.14^{ab}	0.05 ± 0.01^{a}
LRA1	3.55 ± 0.01^{b}	8.25 ± 0.09^{bc}	1.64 ± 0.10^{a}	0.04 ± 0.01^{a}
LPC1 + LRA1	3.52 ± 0.01^{b}	8.27 ± 0.10^{bc}	1.48 ± 0.12^{ac}	0.04 ± 0.01^{a}
LPL2 + LRA1	3.54 ± 0.02^{b}	8.09 ± 0.11^{bc}	1.14 ± 0.13^{bd}	0.05 ± 0.01^{a}
LPC1 + LPL2 + LRA1	3.55 ± 0.03^{ab}	8.87 ± 0.21^{a}	0.89 ± 0.25^{bd}	0.04 ± 0.01^{a}

LPL2; *Lactobacillus plantarum*, LPC1; *Lactobacillus paracasei*, LRA1; *Lactobacillus rhamnosus*†, LS mean±SE. Within a column, LS mean bearing different superscripts are significantly different ($p < 0.05$).

Table 2. Effect of *Lactobacillus* inoculum on the nutritional quality of maize silage at 6 weeks ensiling

Inoculum	CP (%)†	NDF (%)†	ADF (%)†	DMD (%)†	ME (MJ/kg DM)†
Control	7.63 ± 0.15^{ab}	67.32 ± 6.40^{ab}	31.08 ± 2.51^{a}	64.69 ± 1.95^{a}	9.69 ± 0.30^{a}
LPC1	7.79 ± 0.08^{ab}	67.45 ± 3.49^{ab}	34.70 ± 1.36^{a}	61.86 ± 1.06^{a}	9.26 ± 0.16^{a}
LPL2	8.04 ± 0.08^{a}	64.50 ± 3.51^{b}	34.23 ± 1.37^{a}	62.24 ± 1.07^{a}	9.30 ± 0.16^{a}
LRA1	7.83 ± 0.59^{ab}	64.49 ± 2.58^{b}	35.37 ± 1.01^{a}	61.35 ± 0.79^{a}	9.15 ± 0.12^{a}
LPC1 +LRA1	7.36 ± 0.07^{c}	73.98 ± 2.99^{a}	35.45 ± 1.17^{a}	61.28 ± 0.91^{a}	9.21 ± 0.14^{a}
LPL2 + LRA1	7.74 ± 0.78^{ab}	66.51 ± 3.38^{b}	36.58 ± 1.32^{a}	60.40 ± 1.03^{a}	9.01 ± 0.16^{a}
LPC1 + LPL2 + LRA1	7.79 ± 0.15^{ab}	71.92 ± 6.35^{ab}	37.37 ± 2.49^{a}	59.79 ± 1.94^{a}	8.98 ± 0.29^{a}

LPL2; *Lactobacillus plantarum*, LPC1; *Lactobacillus paracasei*, LRA1; *Lactobacillus rhamnosus*†, LS mean±SE. Within a column, LS mean bearing different superscripts are significantly different at $p < 0.05$ probability level. CP; crude protein, NDF; neutral detergent fibre, ADF; acid detergent fibre, DMD; dry matter digestibility, ME; metabolizable energy.

in shaping silage fermentation and demonstrate the potential of locally derived inoculants for improving maize silage quality under tropical conditions.

Conclusion

Inoculated silages showed superior fermentation quality and nutritional stability compared with the uninoculated control. Inoculation particularly with *L. plantarum* (LPL2) and *L. paracasei* (LPC1), improved crude protein preservation and maintained the overall nutrient composition of maize silage under tropical conditions. The triple-species (LPC1 + LRA1 + LPL2) inoculant enhanced carbohydrate fermentation and lactic acid production, contributing to improved silage stability during storage. *Lactobacillus paracasei* (LPC1) alone

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RACE TYPING OF *Pyricularia oryzae* INFECTING RICE AND FINGER MILLET IN SRI LANKA



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Rice (*Oryza sativa*) and finger millet (*Eleusine coracana*) are among the world's most important staple food crops. The main cuisine consumed by Sri Lankans is rice, and rice occupies ~34% of the total cultivated area in the country. After rice and corn, finger millet is the third major cereal grown in Sri Lanka.

Blast disease, caused by the fungal pathogen *Pyricularia oryzae Cavara*, is one of the most destructive and widely distributed plant diseases affecting cereal crops with significant economic value, like rice and finger millet. It is estimated that rice blast causes $66 billion in losses worldwide each year, with grain losses sufficient to feed approximately 60 million people. Blast disease affects finger millet at all growth stages, and the most harmful types are finger and neck blast, which can reduce biomass and average yield annually by up to 100%.

In Sri Lanka, blast disease impacts rice and finger millet at every stage of crop development. Even though local statistics are unavailable, farmers in rice cultivation suffered a 100% yield loss at the panicle stage as a result of neck blast. According to previous studies, local rice varieties are highly susceptible to neck blast even though they are resistant to leaf blast.

In plants, defense against specialized pathogens is triggered by single dominant or semi-dominant genes known as resistance genes (R genes) that interact with avirulence (AVR) genes in pathogens. Host plants mediate resistance through R genes that directly or indirectly recognize pathogen AVR genes and trigger defense responses.

To date, over 40 AVR genes have been identified in *P. oryzae*, with several of them successfully cloned. The study about AVR genes and R genes is crucial for enhancing the understanding of pathogen variability and for informing breeding strategies aimed at improving disease-resistant varieties.

Gene pyramiding, which combines multiple R genes into a single variety, can strengthen resistance and help defend against a greater diversity of pathogen strains.

This study investigated the diversity of AVR genes in a collection of *P. oryzae*, isolates infecting rice and finger millet in Sri Lanka and the distribution of a selected set of AVR genes across different climatic zones, different cultivation seasons, and the hosts. The findings can inform development of more effective and durable blast disease management strategies. Furthermore, the findings will help broaden the spectrum of resistance in rice and finger millet cultivars grown in Sri Lanka against blast disease, ensuring sustainability of rice and finger millet production in the country.

Methodology

A total of 74 blast-infected samples were collected island-wide, comprising 60 finger millet samples from the dry (13) and intermediate (47) zones and 14 rice samples from the dry (7), intermediate (2), and wet (5) zones in yala and maha cultivation seasons. Pure cultures of the pathogen were obtained.

Genomic DNA of seventy-four *P. oryzae*, isolates were extracted using the Wizard® Genomic DNA Purification Kit. The isolates were screened using gene-specific PCR for 13 AVR genes. The PCR-amplified products were visualized on 1% agarose electrophoresis in 1 × TAE buffer. Run for 90 minutes at 70 V.

Presence and absence of bands were scored as 1 and 0, respectively, and scored into a data matrix, and allele frequencies were analyzed using descriptive statistics. Heat maps were generated across the host, cultivating season, and the climate zone of the sample in R version 4.3.2 (R Core Team, 2023). The genetic diversity among the population was evaluated using GenAlEx v 6.5 (Peakall and Smouse, 2006, 2012) frequency-based analysis.

From the data matrix, Cluster analysis (CA) was carried out using the statistical software Minitab (version 17). Using the data obtained from the cluster analysis, samples were mapped in their GPS locations according to the cluster, climate zone, and the growing season of the host using computer software, Esri. (2023). *ArcGIS Pro* (Version 3.1.0).

Results and Discussion

Overall, *AVR-CO39, AVR-Pib, AVR-Pit, ACE1,* and *AVR-Pizt* were found in over 90% of the pathogen population, while *AVR-Pii* and *AVR-Pi54* were found in 100% of the isolates, suggesting that these genes were highly conserved in the Sri Lankan *P. oryzae* populations. In contrast, *AVR-Pi9, AVR-Pikz,* and *AVR-Pita* were detected in less than 50%, with *AVR-Pita* detected in only 8% of the isolates. Interestingly, *AVR-Pia* was absent from rice isolates in all climate zones and cultivation seasons, possibly a result of clonal elimination as a result of wide cultivation of resistant varieties. Distinct spatial and temporal patterns were revealed among the isolates. While *AVR-Pia, AVR-Pikz, AVR-Pita, AVR-Pi9,* and *AVR-Pi15* varied across climatic zones and seasons, *AVR-Pii, AVR-Pi54, AVR-Pit, ACE1,* and *AVR-Pizt* were consistently present in all climate zones and cultivation seasons. Finger millet isolates showed the greatest seasonal fluctuation between Yala and Maha, with variations in the occurrence of *AVR-Pi9, AVR-Pi15*, and *AVR-Pia* indicating seasonal changes in pathogen populations.

Rice isolates showed relatively stable AVR gene profiles across climatic zones, although *AVR-Pikz* and *AVR-Pita* remained consistently rare or absent. The results identified both AVR genes that were rare and variable across geographic regions and growing seasons, as well as frequent AVR genes that were consistently present regardless of host, climate zone, or season.

Conclusion

The frequent AVR genes represent promising targets for the informed deployment and pyramiding of resistance genes in rice and finger millet varietal development, as they are broadly conserved within the pathogen population and therefore offer potential for durable blast disease management. However, AVR genes can represent moving targets, as evidenced by the significant variability observed across host species, climatic zones, and cultivation seasons. Consequently, regular pathogen surveillance is strongly recommended to support adaptive and sustainable resistance breeding strategies.

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DUCKWEED AS A SUSTAINABLE NUTRIENT- RICH RESOURCE: BIOCHEMICAL CHARACTERIZATION, CULTIVATION OPTIMIZATION, AND COOKIE FORTIFICATION POTENTIAL



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Ensuring access to nutritionally balanced and sustainable food resources remains a critical global challenge, particularly as a significant portion of the population continues to lack adequate nutrition while the demand for high-quality nutrients is steadily increasing. In developing regions, insufficient dietary intake contributes to protein–energy malnutrition and micronutrient deficiencies, adversely affecting growth, immune function, and increasing susceptibility to chronic non-communicable diseases. Consequently, the identification of sustainable, nutrient-dense food sources is essential for enhancing global food security and nutritional well-being.

Plant-based resources have emerged as promising alternatives due to their sustainability and rich nutritional profiles. Among these, duckweed, a small floating aquatic plant belonging to the family Lemnaceae, has attracted growing interest. It is widely distributed in freshwater environments and is characterized by rapid growth and high biomass productivity, making it a strong candidate for sustainable food and feed production.

Duckweed is nutritionally rich, containing proteins, carbohydrates, dietary fiber, lipids, vitamins, and minerals, along with bioactive compounds such as phenolics, flavonoids, carotenoids, and phytosterols that contribute to various health benefits. However, its nutritional composition and productivity are influenced by species variation and cultivation conditions, necessitating optimization of growth parameters. In addition, effective extraction and characterization of duckweed proteins are important for understanding their structural, functional, and techno-functional properties for food applications.

Beyond its nutritional value, duckweed offers potential for incorporation into value-added food products. Bakery items such as cookies, widely consumed due to their convenience and acceptability, serve as suitable vehicles for nutritional fortification. The incorporation of duckweed powder into such products may enhance their nutritional quality and provide additional health benefits. In Sri Lanka, favorable environmental conditions support the growth of various duckweed species; however, their full nutritional, biochemical, and application potential remains insufficiently explored.

This study aimed to evaluate the nutritional, biochemical, and techno-functional potential of selected duckweed species in Sri Lanka for sustainable nutrient production and the development of value-added food products. Specifically, it seeks to investigate the nutritional composition and bioactive properties of selected species, assess their growth performance, protein yield, and

mineral content under different fertilizer treatments, and to extract and characterize duckweed proteins using appropriate methods while evaluating their amino acid profiles and functional properties. Furthermore, the study aimed to develop functional cookies by partially substituting wheat flour with duckweed powder and to evaluate their nutritional quality, sensory acceptability, antioxidant activity, enzyme inhibition potential, and microbial safety.

Methodology

This study was designed as a multi-phase investigation to systematically evaluate duckweed as a sustainable and nutrient-rich resource for food applications. In the initial phase, four duckweed species; *Spirodela polyrhiza* (SP), *Lemna minor* (LM), *Lemna perpusilla* (LP), and *Landoltia punctata* (LaP) were collected from local freshwater reservoirs and subjected to bioactivity evaluation. Their antioxidant potential, enzyme inhibitory activities, and other bioactive properties were assessed using standard *in vitro* assays, providing insight into their potential health-promoting effects.

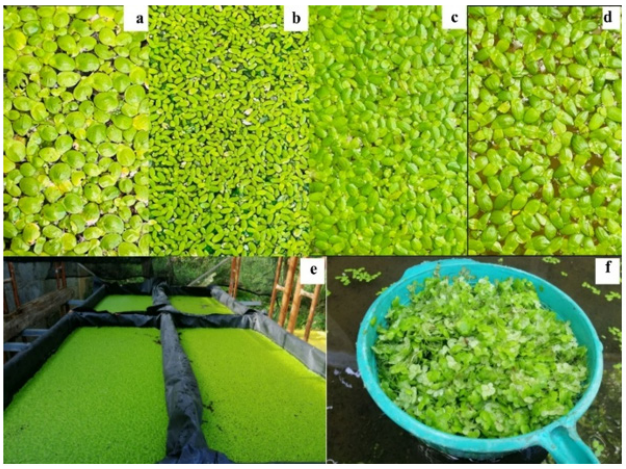


Figure 1: Examined duckweed varieties, (a) *Spirodela polyrhiza* (b) *Lemna minor* (c) *Lemna perpusilla* (d) *Landoltia punctata*(e) Sample cultivation, (f) Harvested Duckweed

In the second phase, these species were cultivated under controlled conditions using three fertilizer treatments: organic manure (OM), inorganic fertilizer (IM), and a combined treatment (CM). Growth performance and biomass production were monitored to evaluate cultivation efficiency, while protein content and mineral composition were quantified to assess nutritional quality under different nutrient regimes. Proteins were subsequently extracted from the harvested biomass using alkaline extraction (AE) and salt extraction (SE) methods. The extracted proteins were then characterized to determine their suitability for food applications. Amino acid composition was analyzed using High Performance Liquid Chromatography (HPLC), while structural and functional group characteristics were examined using Fourier Transform Infrared Spectroscopy (FTIR) and Raman Spectroscopy, enabling a detailed understanding of protein quality and functionality.

In the final phase, the practical applicability of duckweed as a food ingredient was explored through product development. Functional cookies were formulated by partially replacing wheat flour with duckweed powder at substitution levels ranging from 10% to 40%. A blend of SP and LP in a 1:1 ratio was selected to balance nutritional enhancement and product acceptability. The developed products were evaluated for their nutritional composition, functional properties, and overall quality, demonstrating the feasibility of incorporating duckweed into commonly consumed foods as a value-added, sustainable ingredient.

Results and Discussion

The findings of this study demonstrate that the four duckweed species possess considerable nutritional and functional potential, although marked interspecific differences were observed in their bioactive properties. Among the species investigated, SP exhibited the strongest antioxidant activity, suggesting a superior capacity to scavenge reactive oxygen species. This enhanced antioxidant potential is likely associated with its higher abundance of phenolic compounds, particularly rutin, which was identified as the predominant polyphenol in all four species. Rutin is well recognized for its antioxidant, anti-inflammatory, and antidiabetic activities, and its presence may have contributed substantially to the biological activities observed in this study.

The enzyme inhibitory assays further demonstrated the therapeutic potential of duckweed. Both SP and LaP showed strong α-amylase inhibitory activity, indicating their potential to reduce carbohydrate digestion and moderate postprandial blood glucose levels. In addition, SP exhibited the greatest lipase inhibitory activity, suggesting possible applications in reducing dietary fat absorption and supporting weight management. These findings indicate that duckweed contains bioactive constituents capable of influencing metabolic pathways associated with diabetes and obesity, highlighting its promise as a functional food ingredient.

The antimicrobial assays revealed distinct differences among the duckweed species. While SP showed effective antimicrobial activity against selected bacterial and fungal strains, LaP demonstrated broader-spectrum antimicrobial activity against multiple microorganisms. These observations suggest that different duckweed species may produce varying profiles of antimicrobial phytochemicals, making them promising sources of naturally derived antimicrobial agents for food

preservation and health-related applications.

The protective effects of duckweed extracts were further supported by DNA protection assays, in which SP and LP effectively prevented oxidative DNA damage. Together with the low toxicity observed in the brine shrimp lethality assay, these findings indicate that duckweed extracts possess favourable safety characteristics while retaining significant biological activity, supporting their potential use in functional foods and nutraceutical formulations.

The cultivation experiments clearly demonstrated that nutrient management significantly influenced duckweed productivity. Application of inorganic fertilizer resulted in the greatest improvements in biomass accumulation and protein production, with LP exhibiting the highest growth performance under optimized nutrient conditions. The enhanced productivity is likely attributable to the increased availability of nitrogen, which promotes chlorophyll synthesis, photosynthetic efficiency, and protein biosynthesis. Although poultry manure also improved protein content, its effects were generally less pronounced, indicating that optimized inorganic nutrient supplementation provides more favourable conditions for rapid biomass production.

Protein extraction efficiency was significantly affected by the extraction method. Salt extraction consistently produced higher protein yields than alkaline extraction across the studied duckweed species, particularly for LP. This improved recovery is likely due to the greater solubility of salt-soluble proteins and reduced protein denaturation during extraction. Furthermore, FTIR spectroscopy, Raman spectroscopy, and amino acid profiling confirmed that the extracted proteins possessed desirable structural characteristics and a balanced amino acid composition, supporting their suitability for food and feed applications.

Heavy metal analysis demonstrated that duckweed cultivated under all fertilizer treatments accumulated essential minerals while maintaining toxic metal concentrations within internationally accepted safety limits. These findings indicate that controlled cultivation conditions can produce nutritionally valuable duckweed biomass without compromising food safety.

The practical application of duckweed as a functional food ingredient was demonstrated through cookie formulation. Increasing duckweed incorporation enhanced the protein, fibre, and mineral contents of the cookies; however, higher substitution levels adversely affected sensory characteristics. Cookies containing 10% duckweed powder achieved the best balance between improved nutritional quality and consumer acceptability. Importantly, antioxidant activity and α-amylase inhibitory activity were retained after baking, suggesting that the major bioactive compounds remained relatively stable during thermal processing. These results highlight the potential of duckweed powder as a sustainable functional ingredient for the development of nutrient-enriched bakery products with additional health-promoting properties.

Conclusion

This study demonstrates that the four naturally occurring duckweed species, *Spirodela polyrhiza*, *Lemna minor*, *Lemna perpusilla*, and *Landoltia punctata*, are promising sustainable sources of nutrients and bioactive compounds with potential applications in food and nutraceutical industries. The findings show that optimized cultivation practices, particularly the use of inorganic fertilizer, significantly enhanced duckweed growth and protein productivity while maintaining heavy metal concentrations within acceptable safety limits. Salt extraction proved to be an effective method for protein recovery, supporting its potential for industrial applications. Furthermore, incorporation of duckweed powder into cookies successfully improved their nutritional value while maintaining acceptable sensory quality, demonstrating its suitability as a functional food ingredient. Overall, these findings highlight duckweed as a safe, sustainable, and economically viable resource for developing nutrient-enriched foods and functional ingredients, warranting further studies on large-scale cultivation, product development, and clinical evaluation.

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CHEMISTRY AND BIOACTIVITY OF SECONDARY METABOLITES, PRODUCED BY ENDOPHYTIC FUNGI FROM *Coccinia grandis, Costus speciosus* AND *Gymnema sylvestre*



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Natural products have historically served as an indispensable foundation for the discovery and development of pharmaceuticals, agrochemicals, nutraceuticals, and cosmeceuticals. Despite the rapid advancement of synthetic chemistry, natural products continue to contribute significantly to modern drug discovery due to their remarkable structural diversity, biological specificity, and pharmacological effectiveness. Among the various natural sources, microorganisms, particularly endophytic fungi, have emerged as a highly promising yet underexplored reservoir of biologically active secondary metabolites.

Endophytic fungi are microorganisms that asymptomatically colonize internal healthy plant tissues and establish complex symbiotic relationships with their host plants. These associations enable endophytes to biosynthesize chemically diverse metabolites that often exhibit potent biological activities, including antioxidant, antimicrobial, antifungal, anticancer, antidiabetic, anti-inflammatory, and enzyme inhibitory properties.

The discovery of important microbial-derived drugs such as penicillin and fungal-derived paclitaxel has greatly stimulated scientific interest in fungal natural products and highlighted the immense pharmaceutical value of microbial secondary metabolites. In particular, endophytic fungi associated with medicinal plants have attracted considerable attention because they possess the unique metabolic capability to produce compounds analogous or superior to those synthesized by their host plants. Consequently, endophytes isolated from medicinal plants represent a valuable and sustainable alternative source for the discovery of novel therapeutic lead compounds without excessive exploitation of plant resources. Medicinal plants such as *Coccinia grandis*, *Costus speciosus*, and *Gymnema sylvestre* are widely recognized in traditional and Ayurvedic medicine for their antidiabetic and therapeutic properties.

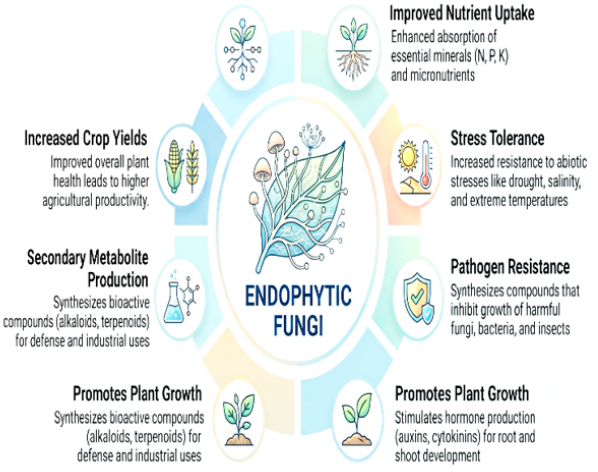


Figure 1: Features of Endophytic fungi

Previous pharmacological investigations have demonstrated that these plants possess significant antioxidant, antimicrobial, anti-inflammatory,

hypoglycemic, hepatoprotective, and enzyme inhibitory activities. However, despite the extensive medicinal importance of these host plants, the chemistry and biological potential of their associated endophytic fungi remain insufficiently investigated.

Therefore, the present study was undertaken to isolate, identify, and characterize endophytic fungi inhabiting the leaves of these medicinal plants and to investigate their secondary metabolites as potential sources of biologically active compounds.

Methodology

Endophytic fungal strains were isolated from healthy leaf tissues of *Coccinia grandis*, *Costus speciosus*, and *Gymnema sylvestre* following optimized surface sterilization and aseptic culturing techniques. The isolated fungi were identified through morphological characterization and molecular analysis. Large-scale fermentation in potato dextrose broth was performed to stimulate the production of fungal secondary metabolites, which were subsequently extracted using ethyl acetate and methanol. Bioactive compounds were purified through sequential chromatographic techniques including silica gel column chromatography, Sephadex LH-20, RP-18 chromatography, PTLC, HPLC, and LC-MS, while their chemical structures were elucidated using UV, IR, MS, and NMR spectroscopic analyses.

Comprehensive bioactivity screening was conducted using both crude extracts and purified compounds to evaluate their pharmaceutical and biological potential. Antioxidant capacity was determined through DPPH, ABTS, and FRAP assays, while phytotoxic effects were assessed using lettuce seed germination inhibition studies. Antifungal activity was evaluated against fungal pathogens using TLC bioautography. In addition, enzyme inhibitory assays targeting α-amylase, α-glucosidase, pancreatic lipase, and acetylcholinesterase were performed to investigate the potential antidiabetic, anti-obesity, and neuroprotective properties of the fungal metabolites. These bioassays collectively provided a systematic evaluation of the biological significance and therapeutic potential of the isolated endophytic fungal metabolites.

Results and Discussion

This study was aimed to isolate, identify and evaluate secondary metabolites from endophytic fungi associated with leaves of three medicinal plants, *Coccinia grandis*, *Costus speciosus*, and *Gymnema sylvestre*. From each plant species, one fungal strain was successfully isolated and identified. The strains were determined to be *Xylaria berteri*, *Edenia gomezpompae*, and *Colletotrichum siamense*, respectively. Among them, the EtOAc extract of *E. gomezpompae* demonstrated remarkable antioxidant, phytotoxic, and enzyme inhibitory activities, showing strong DPPH radical scavenging activity (IC_{50} = 198.31 mg L^{-1}), significant FRAP and ABTS activities, complete lettuce seed germination inhibition at higher concentrations, and potent α-amylase inhibition with 100% inhibition at 1000 ppm.

Chemical investigation of the EtOAc extract of X. berteri yielded three compounds, 1,3,6-trihydroxy-8-methylxanthone, 4-hydroxybenzoic acid and xylarenone A; *E. gomezpompae* afforded two compounds, preussomerin EG2 and leptosphaerodione; *C. siamense* furnished three compounds acropyrone, uridine, and cytidine. Structural elucidation was achieved through detailed UV, GC-MS, ^{1}H NMR, and ^{13}C NMR spectroscopic analyses. A major finding of the study was the first reported isolation of 1,3,6-trihydroxy-8-methylxanthone and 4-hydroxybenzoic acid from *X. berteri*.

Additionally, isolated compounds exhibited promising α-glucosidase inhibitory activities, particularly leptosphaerodione, which showed 99% inhibition with an IC_{50} value of 2.39 μg mL^{-1}, highlighting its strong antidiabetic potential.

Overall, the findings demonstrate that medicinal plant-associated endophytic fungi are rich sources of structurally diverse and biologically active secondary metabolites with significant antioxidant, phytotoxic, antifungal, and enzyme inhibitory properties, supporting their potential application in pharmaceutical and drug discovery research.

Conclusion

In conclusion, this study successfully demonstrated that endophytic fungi associated with medicinal plants are prolific sources of structurally diverse and biologically significant secondary metabolites with promising pharmaceutical potential. Endophytic fungal strains isolated from *Coccinia grandis*, *Costus speciosus*, and *Gymnema sylvestre* were effectively identified, cultured, and chemically investigated, leading to the isolation of several bioactive metabolites including 1,3,6-trihydroxy-8-methylxanthone, 4-hydroxybenzoic acid, xylarenone A, preussomerin EG2, leptosphaerodione, acropyrone, uridine, and cytidine.

Among the investigated fungi, the EtOAc extract of *Edenia gomezpompae* exhibited remarkable antioxidant, phytotoxic, antifungal, and enzyme inhibitory activities, indicating the presence of potent bioactive constituents. Significant α-glucosidase inhibitory activities were observed for isolated metabolites, particularly leptosphaerodione, further emphasizing the therapeutic potential of these fungal metabolites as prospective antidiabetic agents. The study also revealed that semi-polar EtOAc fractions generally possessed stronger biological activities than methanolic fractions, suggesting that biologically active secondary metabolites are preferentially enriched in moderately

polar solvent systems.

Overall, these findings strongly support the concept that medicinal plant-associated endophytic fungi represent an underexplored reservoir of novel natural products with valuable pharmacological properties. Therefore, further purification, mechanistic investigations, toxicity studies, and large-scale biotechnological exploration of these fungal metabolites may lead to the discovery and development of new therapeutic agents for pharmaceutical applications.

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DETERMINATION OF DESCRIPTOR VALUES FOR SELECTED CONSTITUENTS IN CINNAMON, TO DETERMINE THEIR DISTRIBUTION LEVELS IN ENVIRONMENTAL COMPARTMENTS



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There are more than 250 species of cinnamon, and among them, the Ceylon cinnamon, *Cinnamomum zeylanicum,* is the most important species from an economic perspective. It has a higher demand due to the higher level of trans-cinnamaldehyde, which is essential for the unique aroma and taste, and also a lower level of coumarin, which is a potential hepatotoxic compound, compared to other cinnamon species.

The unique properties of Cinnamon are due to the useful organic compounds found in Cinnamon in almost every part of the tree, such as inner bark, leaves, fruits, flowers, and even in the roots. These compounds have diverse applications in various fields, including medicine, food science, and the perfumery industry.

When it comes to the commercial manufacturing of cinnamon products, it is important to determine the concentration levels during production, usage, and waste handling. The conventional methods that are used in this process are costly and require a significant amount of human and technical resources. But the Abraham solvation parameter model, which is based on the Quantitative Structure Property Relationships approach, is a low cost and less time-consuming method that can be devised to predict physiochemical properties using easily accessible properties (surrogate models). The most accepted model based on the linear free energy relationships is the solvation parameter model developed by Michael H. Abraham and co-workers, which was developed to describe the solvation processes based on the cavity model of solvation. In this model, a series of descriptors are used to represent the solute properties, and a set of system constants are used to represent the complementary solvent properties.

Based on the free energy change taking place during this process, Abraham and the co-workers formulated the following equations, for the solute transfers between the gas phase and a condensed phase,

$$\log SP = c + eE + sS + aA + bB + lL \quad (1)$$

For the solute transfers between two condensed phases,

$$\log SP = c + eE + sS + aA + bB + vV \quad (2)$$

These equations are linked with the solvent—solute interactions. The simple letters are related to the properties of the solvent and known as system constants, while the capital letters or the solute descriptors are related to the properties of solutes. Here, **SP** is a Solute Property that can be described by an equilibrium constant or any other free energy-related term; the retention factor and partition constant are some examples. The capital letters **E** stand for the excess molar refraction, **S** for dipolarity/polarizability, **A** for hydrogen-bond acidity, **B** for hydrogen-bond basicity, **L** is the gas-hexadecane partition coefficient, and **V** is McGowan's characteristic volume, respectively. Simple letters **e** denotes excess molar refraction, **s** for dipolarity/polarizability, **a** for hydrogen-bond basicity (as hydrogen bond-base solvent will interact with a hydrogen-bond acid solute), **b** the hydrogen-bond acidity, **l** is the cavity formation/dispersion interactions of the system for solute transfer from a gas phase to a condensed phase, and the **v** difference in cavity formation and residual dispersion interactions of a biphasic system for solute transfer between two

condensed phases. The system constants are unique for a particular system, while the solute descriptors are similarly unique for a particular solute.

In this research project, the focus is on the solute descriptors and their determination for several compounds found in cinnamon. Systems with known system constants and solute properties are needed to determine unknown descriptor values. The solute descriptors for the compounds and the system constants for various systems can be determined by computational methods, experimental methods, and by combining computational and experimental methods.

In computational methods, the descriptors are determined using only the structural properties. This process can be mainly categorized as group contribution methods, quantum chemical calculation methods, and machine learning using deep neural networks.

When considering experimental methods, the chromatographic methods are ideal as they accurately represent the solute transfer processes related to solvation parameter models. Combined methods that consist of computational and experimental methods are considered ideal as they are efficient, fast, and produce chemically significant descriptors.

For the determination of solute descriptors, a system with known system constants has to be used so that the unknown or partially determined solute descriptors can be determined by applying to equations 1 and 2. This system can be a chromatographic stationary phase or a liquid-liquid partition system. The E and V descriptors are calculated using computational methods, while the others are determined using experimental methods. Mainly, the Gas chromatographic (GC) retention factor values and partition constant values are used as the experimental data.

The solvation parameter model is practically applied over a wide range of fields including environmental science, medicine, and industry. The accuracy of the predictions has enabled this model to be used to such an extent. The mathematical models are constructed based on the solvation parameter model so that researchers can easily use a surrogate model or even the determined descriptors to get useful predictions.

Methodology

The solute descriptor values were determined for seven volatile compounds found in cinnamon: benzyl cinnamate, ethyl cinnamate, methyl cinnamate, cinnamaldehyde, citronellal, eugenol acetate, and cinnamyl acetate. The research methodology carried out can be mainly divided into three parts: determination of log (Standard retention factor) values, partition constant values, and finally the analysis of data to determine solute descriptors.

Agilent 7890 B gas chromatographic system fitted with a split/splitless injector and flame ionization detector was used for the research project. The log (standard retention factor) values were determined in different GC stationary phases at different temperatures. For this, seven stationary phases were used to prepare calibration plots of log (standard retention factor) value vs log (experimental retention factor). The stationary phases used were DB-1701 [(14% cyanopropyl-phenyl)-methylpolysiloxane], DB-Wax [Polyethylene glycol], HP-5 [(5%-phenyl)-methylpolysiloxane], HP-88 [(88% Cyanopropyl) aryl-polysiloxane], Rtx-OPP [Proprietary stationary phase containing Trifluoropropyl Groups], Rxi-17 [Proprietary stationary phase containing Phenyl Methyl groups] and Rtx-440 [Proprietary stationary phase containing Cyanopropyl groups].

These calibration plots were used to determine the Log (standard retention factor) values of the compounds. Isothermal retention factors (k) in the range $-1.25 < \log k < 2.3$ were measured at 20 °C intervals for the columns. The experimental retention factor was calculated from the measurement of the gross retention time and gross column hold-up time. The gross column hold-up time was determined using Methane, which is a non-retained solute.

The partition constants were determined for nearly 20 different liquid - liquid partition systems such as the n-heptane-ethylene glycol system. These systems consisted of two immiscible liquid phases with different polarities. The cinnamon compounds were equilibrated within each of these systems together with an internal standard. 1 μL aliquots from each phase were extracted using a syringe and injected into GC for analysis. The obtained peak area values were used to determine the experimental partition constant values.

The obtained log (standard retention factor) values and partition constant values were used to determine the solute descriptor values. This was carried out with the help of an optimization package, the Solver Algorithm of Microsoft Excel, which has been used in several previous experiments related to the determination of solute descriptors. This process involves assigning descriptors for each compound simultaneously to minimize the standard deviation for the sum of the experimental–model predicted value for log k.

Results and Discussion

The calibration plots, log (standard retention factor) values vs log (experimental retention factor), were obtained with higher R^2 values closer to 1. Figure 1 is the calibration plot obtained for RTX 440 stationary phase at 160 °C. Similar calibration plots were prepared for all the other stationary phases, and the log (standard retention factor) values of the selected cinnamon compounds were determined using them.

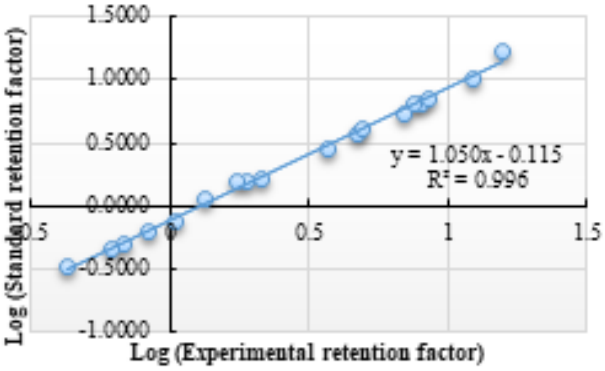


Figure 1: Calibration 440 stationary phase at 160 °C

Table 1: Selected partition constant values determined for Methyl cinnamate in liquid-liquid partition systems.

Solvent system	Average K_p
Heptane-Ethylene glycol	2.221
Heptane-N, N-dimethylformamide	20.911
Heptane-Formamide	1.663
Heptane-Trifluoroethanol	0.250
Isopentyl ether-Ethylene glycol	6.065
Isopentyl ether-Formamide	3.184
Formamide-1,2-dichloroethane	0.064
Triethylamine-Dimethyl sulfoxide	0.365
Triethylamine-Formamide	3.867
Isopentyl ether-Dimethyl sulfoxide	0.258
Octanol-Propylene carbonate	0.692

Table 2: Determined solute descriptors for selected cinnamon

Compound	Descriptor							Standard deviation
	E	S	A	L	B	V	n	
Benzyl cinnamate	1.668	1.487	0.000	8.789	0.716	1.919	92	0.063
Ethyl cinnamate	1.095	1.099	0.000	6.323	0.617	1.452	72	0.046
Methyl cinnamate	1.023	1.156	0.000	5.804	0.559	1.311	68	0.052
Cinnamaldehyde	1.056	1.332	0.000	5.328	0.565	1.112	76	0.068
Citronellal	0.279	0.690	0.000	5.066	0.504	1.490	131	0.037
Cinnamyl acetate	1.041	1.228	0.000	6.017	0.626	1.452	72	0.064
Eugenol acetate	0.901	1.327	0.000	6.385	0.792	1.652	60	0.063

For liquid-liquid partition systems, Table 1 contains selected partition constant values (K_p) obtained for methyl cinnamate. The partition constant values were determined for all the other compounds similarly.

After the data were analyzed with the Solver Algorithm in Microsoft Excel ®. The standard deviation of the residuals (difference between the experimental and the predicted retention factor and partition constant values) serves as the error in the determination of solute descriptors. Table 2 shows the determined solute descriptors. Here, **n** = number of calibrated separation systems with experimental retention factors or partition constants.

The determined solute descriptors were validated using surrogate partition systems linked with the research carried out in the Poole research lab of Wayne State University. The experimental partition constant values and the partition constant values that were predicted using determined solute descriptors show a less deviation from each other, showing the higher accuracy of the obtained solute descriptors.

The octanol-water partition system is one of the systems used for validation. The following model was used to obtain predicted values for the octanol-water partition constant (K_{ow}) using determined solute descriptors:

Table 3: Predicted and experimental K_{ow} values

Compound	log K_{OW}	
	Predicted	Experimental
Benzyl cinnamate	4.40	4.10
Ethyl cinnamate	3.02	2.99
Methyl cinnamate	2.57	2.62
Cinnamaldehyde	1.62	1.90
Citronellal	3.44	3.83
Cinnamyl acetate	2.81	2.64
Eugenol acetate	2.81	2.80

$\text{Log } K_{OW} = 0.103 + 0.641E - 1.102S - 0.201A - 3.392B + 3.799V$ (n = 268 $r_a^2 = 0.995$ F = 11362 SE = 0.121).

Here, **n** is the number of compounds with experimental values used (systems), r_a^2 is the coefficient of determination adjusted to the number of degrees of freedom. F is the Fisher statistic, and SE the standard error. The obtained experimental and predicted values for log K_{ow} are shown in Table 3.

Conclusion

The chromatographic and liquid-liquid partition measurements provide a fast and accurate method for the

determination of solute descriptors. The solute descriptor values have been obtained with lower standard deviation and these can be applied in environmental systems and also in the industrial systems to obtain useful predictions on chemical and physical properties. The obtained descriptor values were validated using partition systems such as octanol-water partition systems.

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NUTRITIONAL COMPOSITION, BIOLOGICAL ACTIVITIES AND VALUE-ADDED PRODUCTS OF *Terminalia catappa* L. SEED KERNEL



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With the increasing demand for sustainable and functional food sources, underutilized plant materials have gained considerable scientific attention worldwide. Many tropical plants possess valuable nutritional and medicinal properties but remain insufficiently explored for food and industrial applications. The effective utilization of such plant resources can contribute to food security, waste reduction, and the development of novel functional foods.

Among these underutilized plant resources, *Terminalia catappa* L. is widely distributed in tropical and subtropical regions including Sri Lanka. The plant is commonly known as tropical almond or Indian almond and is traditionally valued for its shade, ornamental appearance, and medicinal uses. Different parts of the plant, including leaves, bark, fruits, and seeds, have been utilized in traditional medicine for the treatment of various ailments. In Sri Lanka, *T. catappa* mainly exists as purple and yellow cultivars which differ in fruit color and certain biochemical characteristics.

Fruits of *T. catappa* contain a hard shell enclosing an edible seed kernel. Although fleshy fruits are commonly available in many areas, the kernels are often underutilized or discarded despite their potential nutritional value. The presence of two cultivars with distinct physical characteristics further highlights the importance of investigating their compositional and functional properties.



Figure 1: Fruits of *Terminalia catappa* L. from purple and yellow cultivars

Previous studies have mainly focused on the medicinal properties of leaves, bark, and fruits of *T. catappa*, while comparatively less attention has been given to the nutritional composition and functional properties of the seed kernels. The kernels are known to contain considerable amounts of lipids, proteins, minerals, and bioactive compounds with potential health-promoting properties.



Figure 2: Seed kernels of *Terminalia catappa* L.

Furthermore, the residues remaining after oil extraction may still contain valuable nutrients and phytochemicals suitable for food applications. Therefore, the present study was conducted to investigate the nutritional composition, biological activities, and value-added potential of whole kernels and defatted residues obtained from purple and yellow cultivars of *T. catappa*. The study further evaluated the possibility of utilizing these materials in the development of functional food products such as bread spreads and cookies, thereby promoting the sustainable utilization of this underexploited plant resource.

Methodology

Mature fruits of purple and yellow cultivars of *T. catappa* were collected and the kernels were separated manually. The kernels were subjected to proximate analysis to determine moisture, fat, protein, ash, and carbohydrate contents. Mineral composition was analyzed using standard analytical techniques. Oil extraction was carried out using a cold-press oil expeller, and the remaining materials were collected as defatted residues.

Different solvent extracts of whole kernels and defatted residues were prepared using hexane, ethyl acetate/dichloromethane, and methanol. The extracts were evaluated for total phenolic content (TPC), total flavonoid content (TFC), antioxidant activities, and enzyme inhibitory activities. Antioxidant potential was assessed using DPPH, ABTS, and FRAP assays, while anti-hyperglycemic activity was evaluated using α-amylase and α-glucosidase inhibition assays. Lipase inhibitory activity was used to assess anti-obesity potential.

The extracted oils were characterized using physicochemical analyses, fatty acid profiling, Differential Scanning Calorimetry (DSC), and Fourier Transform Infrared (FTIR) spectroscopy. FTIR analysis was also used to characterize crude extracts and defatted residues.

Value-added food products including bread spreads and cookies were developed using whole kernels and defatted residues. Sensory evaluation, texture analysis, proximate analysis, shelf-life stability, peroxide value, free fatty acid value, total plate count, and yeast and mold count analyses were conducted to determine product quality and consumer acceptability.

Results and Discussion

The findings revealed that both purple and yellow cultivars of *T. catappa* seed kernels are rich in fat, protein, and essential minerals, indicating their nutritional potential as a food source. Unsaturated fatty acids were predominant, with oleic acid identified as the major fatty acid in both cultivars.

Methanol extracts showed the highest total phenolic content (9.63 – 17.77 mg of GAE/g of extract) and strongest antioxidant activities in DPPH (IC_{50} value = 409.84 ± 0.11 mg L^{-1}), FRAP (116.12 ± 11.80 µmole of $FeSO_4$ / g of crude extract) and ABTS (IC_{50} value = 723.44 ± 0.05 mg L^{-1}) assays. The yellow cultivar demonstrated comparatively higher antioxidant potential. Ethyl acetate and methanol extracts also exhibited strong α-glucosidase inhibitory activity (IC_{50} value = 104.13 - 312.52 mg L^{-1}), suggesting anti-hyperglycemic potential.

The extracted oils showed high unsaturation and good thermal stability, while the defatted residues remained rich in protein, minerals, and phenolic compounds after oil extraction. The yellow cultivar residues further demonstrated notable α-amylase and lipase inhibitory activities, indicating possible anti-obesity potential.

Value-added products developed using whole kernels and defatted residues showed good sensory acceptability and storage stability. Bread-spreads and cookies remained microbiologically safe during storage, while selected formulations demonstrated favorable texture, taste, and consumer preference. Overall, the study confirmed the potential of *T. catappa* kernels and defatted residues as sustainable functional food ingredients.

Conclusion

This study highlights the significant potential of *T. catappa* seed kernels as a sustainable source of nutrients, bioactive compounds, and functional food ingredients. Both purple and yellow cultivars exhibited strong antioxidant and enzyme inhibitory activities, with the yellow cultivar showing comparatively higher biological activity in several assays.

The oils extracted from the kernels contained beneficial unsaturated fatty acids, while the defatted residues remained rich in proteins, minerals, and phenolic compounds. These findings demonstrate that defatted residues can be successfully utilized in value-added

food formulations rather than being discarded as waste.

The successful development of bread spreads and cookies further confirmed the applicability of *T. catappa* kernels in food product development. The products showed good sensory acceptance, nutritional quality, and storage stability. Therefore, *T. catappa* kernels and defatted residues have strong potential for the development of functional foods and sustainable dietary innovations in Sri Lanka.

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REMEDIATION OF VOLATILE PHENOLIC COMPOUNDS USING COPPER-MODIFIED SYNTHESIZED FAUJASITE Y-ZEOLITE CATALYST



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This research focuses on the remediation of hazardous phenolic volatile organic compounds (VOCs), particularly phenol and chlorophenols, from atmospheric pollution using copper-modified Faujasite (FAU) zeolite catalysts. Phenolic vapours are significant environmental pollutants emitted from industrial operations, combustion processes, pesticides, pharmaceuticals, and petrochemical activities. Their release into the atmosphere contributes to air pollution, secondary pollutant formation, and severe health risks, including respiratory irritation, toxicity, and carcinogenic effects. The study emphasizes chlorophenols such as 3-chlorophenol, 4-chlorophenol, 2,3-dichlorophenol, 3,4-dichlorophenol, 2,4,5-trichlorophenol, and 2,4,6-trichlorophenol (Figure 1) due to their persistence, toxicity, and low biodegradability. These compounds are classified as priority pollutants by international environmental agencies.

Among available VOC remediation techniques, catalytic oxidation using porous materials is identified as an efficient, environmentally friendly, and economically feasible approach. FAU Zeolite Y were selected because of its unique super cage porous structure, high surface area, thermal stability, and tunable acidity, which make them promising material for adsorption and catalytic oxidation applications. The research particularly compared copper-modified Zeolite Y synthesized from direct alumino silicate chemicals (Zeolite CuY) and Sri Lankan Meetiyagoda kaolin (ZK CuY) to analyze adsorption and catalytic oxidation of phenolic vapours.

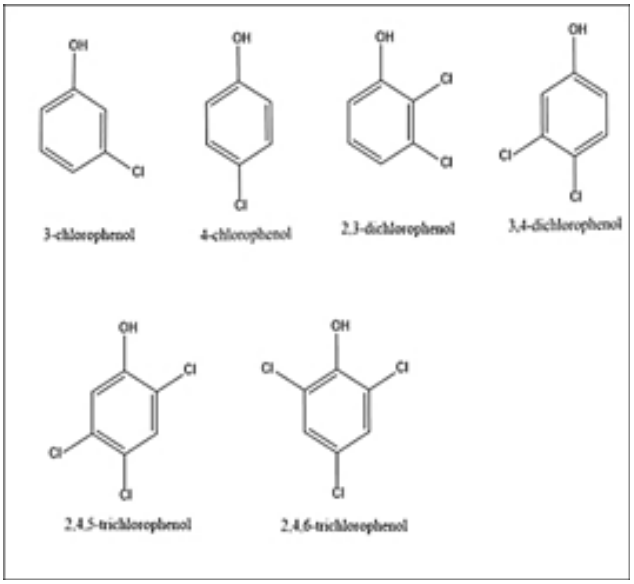


Figure 1: Chemical structures of chlorophenols used for this study

The study involved both experimental and theoretical approaches to understand adsorption mechanisms, catalytic degradation pathways, and the influence of material properties on phenolic vapour removal performance. The research also explored the effect of atmospheric conditions on adsorption and degradation performance, contributing to the understanding of catalyst behaviour under practical operating environments.

Comprehensive adsorption studies were carried out using single-component and multi-component systems, while adsorption isotherm models such as the Freundlich, Langmuir, and Extended Freundlich Isotherms were applied to interpret equilibrium behaviour. In addition, Py-IAST calculations and mixed gas adsorption analyses were employed to predict competitive adsorption behaviour in binary and tertiary gas mixtures. Thermodynamic and kinetic evaluations were also conducted to understand the feasibility and energetics of adsorption processes.

Overall, this work contributes to the advancement of environmentally sustainable phenolic vapour remediation technologies and provides valuable scientific insight into adsorption science, catalyst design, and catalytic oxidation mechanisms.

Methodology

In this study, a seed-assisted hydrothermal synthesis route was adopted without organic structure-directing agents to minimize environmental impact and reduce waste generation. Zeolite CuY was synthesized using 40% (w/w) colloidal silica, $NaAlO_2$, NaOH, NH_4NO_3 and $Cu(NO_3)_2.2.5H_2O$. ZK CuY purified Meetiyagoda kaolin as the aluminosilicate source. Kaolin was calcined to produce metakaolin, which acted as both silica and alumina precursor. Additional silica was incorporated to obtain a higher Si/Al ratio.

The synthesized copper modified-zeolite catalysts were characterized using Fourier transform infrared spectroscopy (FTIR), powder X-ray diffraction (PXRD), scanning electron microscopy (SEM), BET surface analysis, X-ray photoelectron spectroscopy (XPS) and Energy Dispersive X-ray spectroscopy (EDS).

The degradation products analysis was made using the Shimadzu GC/MS-QP2010. Catalytic oxidation experiments were conducted for phenol and chlorophenol vapours under controlled laboratory conditions. The degradation efficiencies of single and mixed phenolic vapours were investigated. Adsorption and oxidation behaviours were also analyzed.

Mixed gas adsorption isotherms of binary and ternary chlorophenol mixtures were calculated using Ideal Adsorbed Solution Theory (IAST) combined with the extended Freundlich isotherm model. Experimental single-component adsorption data of phenolic vapours were first fitted to the Freundlich isotherm, and the obtained parameters were used for multicomponent adsorption calculations. The calculations and isotherm plotting were carried out using Python scripts.

Results and Discussion

The material characterization results and degradation study show the successful synthesis and application of Faujasite-type Zeolite Y catalysts for the degradation of phenol and chlorophenol vapours. Phenol degradation studies revealed that unmodified HY zeolites mainly promoted adsorption, while Cu-modified zeolites enabled actual catalytic degradation. Zeolite CuY achieved the highest phenol removal efficiency, reaching about 60% under optimized inert conditions.

Optimum degradation conditions were identified as 100 °C temperature, 60 minutes reaction time, and 8 mg catalyst dosage. The degradation efficiency increased in the presence of oxygen and hydrogen peroxide, while excess moisture reduced removal efficiency because water molecules hindered access to active catalytic sites. Nearly complete phenol conversion was achieved when peroxide and controlled moisture were simultaneously introduced (Figure 2).

GC/MS analysis identified several intermediate degradation products such as ethanol, acetone, 2-butanone, p-benzoquinone, and organic acids,

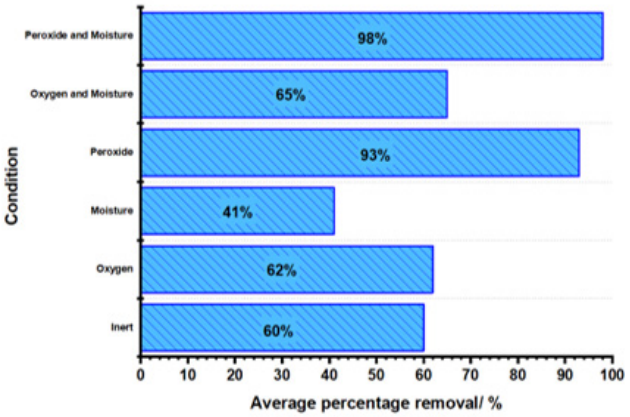


Figure 2: Summary of the phenol conversion under different reaction conditions

indicating progressive oxidation and fragmentation of phenol molecules. Mechanism studies suggested that degradation under inert conditions occurred through reactive oxygen species generated within the zeolite framework, whereas oxygen and peroxide-assisted systems followed a Fenton-like oxidation mechanism involving Cu^+/Cu^{2+} redox cycles.

The study further investigated the degradation of six chlorophenols under various conditions (Figure 4). Under inert conditions, the average degradation efficiency was about 56%, with the degradation order observed as 4-CP > 2,3-dCP = 2,4,6-tCP > 3,4-dCP > 2,4,5-tCP > 3-CP. The results demonstrated that both the number and position of chlorine atoms strongly influenced degradation behaviour. Chlorophenols containing ortho and para chlorine substitutions degraded more readily, whereas meta substitutions slowed degradation due to steric and electronic effects. The catalyst also exhibited competitive adsorption effects in binary and ternary chlorophenol mixtures, where molecular size, chlorine

substitution pattern, and interaction between compounds affected degradation efficiencies.

As a comparative study, both chlorophenol and phenols were subjected to degradation with the ZK CuY catalyst.

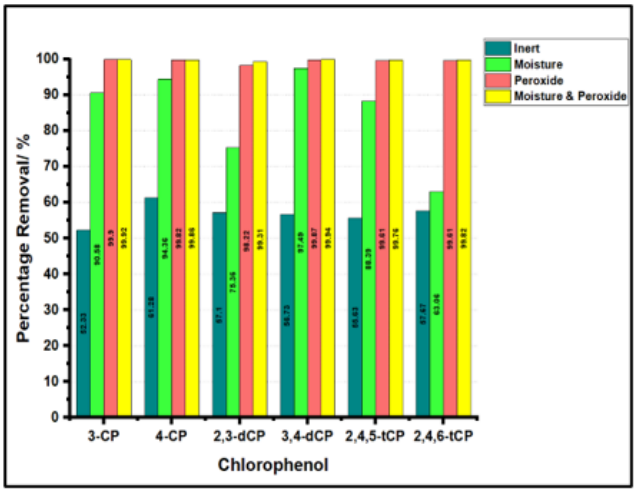


Figure 3: Summary of chlorophenol degradation under different reaction conditions

At optimum inert conditions, phenol conversion from both catalysts seems to be the same. However, ZK CuY exhibits favouritism toward meta-substituted chlorophenols (Figure 5).

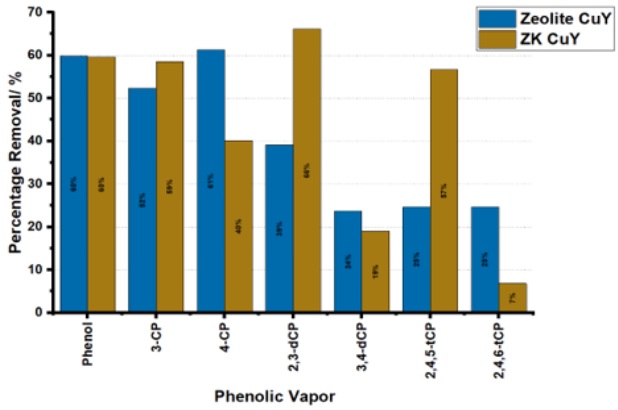


Figure 4: Comparison of percentage removal of phenol and chlorophenol vapour with Zeolite CuY and ZK CuY

Adsorption isotherm studies showed that phenol and chlorophenol adsorption onto HT-Zeolite CuY followed the Freundlich isotherm rather than the Langmuir model, indicating multilayer physisorption on heterogeneous surfaces. Thermodynamic analysis revealed negative Gibbs free energy values, confirming the spontaneous nature of adsorption. Furthermore, py-IAST modelling with the extended Freundlich isotherm was successfully applied to predict binary and ternary adsorption behaviour of chlorophenol mixtures, demonstrating the applicability of computational adsorption modelling for multicomponent VOC systems.

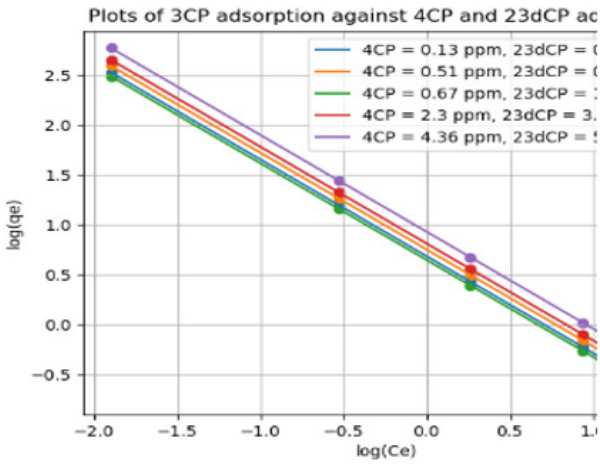


Figure 5: Python script generated an Extended Freundlich IAST Plotting for a ternary mixture of 3-CP, 4-CP and 2,3-dCP

Overall, the study concluded that Cu-modified Faujasite Zeolite Y catalysts, especially Zeolite CuY, possess strong potential as dual-function adsorbent-catalysts for the remediation of phenolic vapours. The catalyst performance depended heavily on crystallinity, metal incorporation, pore structure, and the molecular characteristics of the phenolic compounds. The findings provide valuable insight into the development of efficient and environmentally sustainable catalytic systems for phenolic vapour abatement. The study highlighted that Cu^{2+} species located within zeolite exchange sites contribute strongly to catalytic oxidation behaviour.

Conclusion

The study concluded that copper-modified Faujasite-type Zeolite Y catalysts (Zeolite CuY and ZK CuY) are highly effective materials for the adsorption and catalytic degradation of phenol and chlorophenol vapours. Copper modification significantly enhanced catalytic degradation compared with unmodified HY zeolites, which mainly acted as adsorbents.

The study confirmed that degradation efficiency strongly depends on operational conditions such as temperature, catalyst dosage, reaction time, oxygen availability, moisture content, and hydrogen peroxide addition. Oxygen and peroxide-assisted systems greatly improved degradation through Fenton-like oxidation mechanisms involving Cu^{+}/Cu^{2+} redox cycles, while excessive moisture reduced catalytic activity by blocking active sites. The catalyst successfully degraded phenol and several chlorophenol compounds, and the degradation behaviour was influenced by the number and position of chlorine substituents on the aromatic ring.

Adsorption studies showed that the Freundlich isotherm best described the adsorption process, indicating heterogeneous multilayer adsorption. Thermodynamic

analysis confirmed that adsorption occurred spontaneously, and py-IAST modelling successfully predicted multicomponent adsorption behaviour in binary and ternary chlorophenol mixtures.

Mixed gas adsorption studies revealed competitive adsorption behaviour among chlorophenols, where adsorption performance depended on molecular structure and chlorine substitution. Overall, the developed zeolite catalysts exhibited strong potential for sustainable phenolic vapour remediation and air pollution control.

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FINE-TUNING ELECTRONIC SEMICONDUCTING PROPERTIES OF MOF-74 METAL-ORGANIC FRAMEWORKS TO BE APPLIED IN MOF-SENSITIZED SOLAR CELLS



P.D.T.S.N. Jayasundara *graduated in 2020 with a BSc (Hons) Degree in Chemistry from the University of Sri Jayewardenepura, Sri Lanka. In 2025, she completed her MPhil Degree in Chemistry at the Postgraduate Institute of Science (PGIS), University of Peradeniya, Sri Lanka. Her research focuses on Metal-Organic Frameworks, particularly the MOF-74 series, and their modification using electron-rich guest molecules such as aniline and pyridine derivatives to enhance semiconducting and photovoltaic properties. Her research interests extend across Material Chemistry, Nanoscience, Polymer Chemistry, surface modification, advanced material development, and nanohybrid fabrication. This research aimed to contribute to the development of innovative materials for clean energy, sensing, and environmentally sustainable technologies while advancing the understanding of structure-property relationships in functional materials.*

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Solar energy is one of the most abundant and sustainable renewable energy resources available to address the increasing global energy demand and reduce dependence on fossil fuels. However, the efficiency and stability of conventional photovoltaic technologies are often limited by high production costs, complex fabrication methods, and poor charge-transport properties. Among emerging photovoltaic systems, dye-sensitized and semiconductor-sensitized solar cells have attracted considerable attention due to their low cost, simple fabrication, flexibility, and relatively high efficiency under low-light conditions. Nevertheless, these systems still face challenges, including rapid electron-hole recombination, a narrow light-absorption range, and insufficient long-term stability. Therefore, the development of novel photoactive materials with enhanced light harvesting ability, efficient charge transfer, tunable band gaps, and improved conductivity is essential for advancing next-generation photovoltaic technologies.

Among various advanced materials, metal-organic frameworks (MOFs) have emerged as highly promising candidates for photovoltaic and photoelectronic applications due to their exceptional structural and functional properties. MOFs are crystalline porous materials composed of metal ions or metal clusters coordinated with organic ligands, forming highly ordered three-dimensional frameworks. These materials possess large surface area, tunable pore structures, adjustable electronic properties, and excellent chemical versatility. Such unique characteristics make MOFs attractive for applications in gas storage, catalysis, sensing, environmental remediation, and energy conversion systems, including solar cells. Among different MOF families, MOF-74 materials based on Mg, Co, Ni, and Zn metals have attracted special interest because of their open metal sites, high porosity, and strong interaction capability with guest molecules (Figure 1). The incorporation of electron-rich organic guest molecules into MOF-74 frameworks significantly improves their semiconducting and photovoltaic properties through charge transfer interactions. Guest molecules such as aniline, pyridine, and 4-aminopyridine can interact with the open metal sites within the MOF pores, modifying the electronic structure and reducing the band gap of the framework. These interactions enhance visible light absorption, electron mobility, and charge separation efficiency, thereby improving solar energy conversion performance.

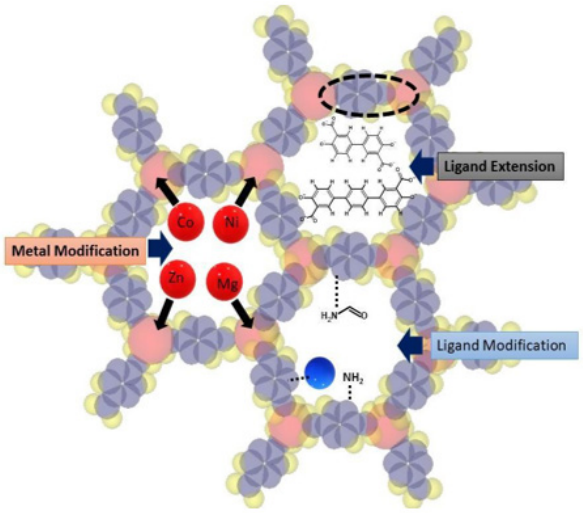


Figure 1: Graphical representation showing metal modification, ligand modification, and ligand extension

Methodology

This study focuses on the synthesis and modification of MOF-74 materials for sensitized solar cell applications through guest molecule encapsulation. Mg-MOF-74, Co-MOF-74, Ni-MOF-74, and Zn-MOF-74 were synthesized using solvothermal methods involving corresponding metal salts and organic linkers under controlled temperature and pH conditions. Electron-rich guest molecules, including aniline, pyridine, and 4-aminopyridine, were introduced into the activated MOF frameworks through a post-synthetic encapsulation process.

The incorporation mechanism was optimized by varying guest molecule encapsulation time, solvent conditions, and activation temperature. The synthesized guest molecule-loaded MOFs were then applied on TiO_2 mesoporous layer, which is deposited onto fluorine-doped tin oxide (FTO) coated glass substrates to fabricate sensitized solar cell photoanodes. The assembled photovoltaic devices were completed using suitable electrolytes and counter electrodes.

The synthesized materials were characterized using Fourier transform infrared spectroscopy (FTIR), powder X-ray diffraction (PXRD), scanning electron microscopy (SEM), solid-state UV-Visible analysis, Mott-Schottky analysis, Cyclic Voltammetric analysis (CV), and electrochemical impedance spectroscopy (EIS). Photovoltaic performance was evaluated using current-voltage (J–V) measurements under simulated solar irradiation conditions.

Results and Discussion

The encapsulation of guest molecules within Co-MOF-74, Ni-MOF-74, Zn-MOF-74, and Mg-MOF-74 resulted in significant modifications to their electronic and structural properties, leading to notable differences in photovoltaic and electrochemical performance. The observed enhancements strongly depended on the nature of the metal center, the electronic properties of the guest molecules, and the incorporation of TiO_2 as a hybrid component.

In the case of Co-MOF-74, the pristine framework exhibited limited conductivity due to the paramagnetic nature of Co^{2+} ions and partial d-orbital overlap. However, guest molecule encapsulation substantially improved its semiconducting behaviour. Among the investigated guest molecules, 4-aminopyridine demonstrated the most pronounced effect, leading to a significant reduction in the optical band gap from 2.72 eV for pristine Co-MOF-74 to 1.62 eV. Similarly, aniline- and p-anisidine-encapsulated systems exhibited reduced band gaps of 1.89 eV and 1.92 eV, respectively. The enhanced electronic properties can be attributed to strong π–d interactions between the aromatic guest molecules and Co^{2+} ions, which facilitated charge delocalization and improved charge carrier mobility.

Electrochemical impedance spectroscopy (EIS) further confirmed the enhanced conductivity of the encapsulated Co-MOF-74 systems. The charge transfer resistance (RCT) decreased dramatically from 1364 Ω for pristine Co-MOF-74 to 32 Ω for the 4-aminopyridine-encapsulated system, indicating significantly improved charge transport properties. The Nyquist plots of certain encapsulated samples displayed dual semicircular features, suggesting the coexistence of bulk and interfacial electrochemical processes. Furthermore, the incorporation of TiO_2 into the Co-MOF-74 framework formed an effective heterojunction that enhanced light harvesting and suppressed electron–hole recombination, resulting in improved photovoltaic performance.

Ni-MOF-74 exhibited superior intrinsic conductivity compared to the other MOF-74 systems due to the d^8 electronic configuration of Ni^{2+} ions. Pyridine encapsulation further enhanced its electrochemical performance through strong host–guest interactions involving the nitrogen lone pair and the Ni^{2+} metal centers. As a result, the RCT value decreased to 12.8 Ω, representing the lowest resistance among all investigated systems. The addition of TiO_2 to Ni-MOF-74 thin films further improved charge separation efficiency and facilitated rapid electron transport, leading to exceptional power conversion efficiencies (PCEs). These findings highlight the strong electronic coupling and enhanced light-harvesting capability of Ni-based MOF systems.

In contrast, Zn-MOF-74 and Mg-MOF-74 initially exhibited insulating characteristics due to the fully filled d^{10} configuration of Zn^{2+} ions and the absence of d-electrons in Mg^{2+} ions. Consequently, these frameworks relied heavily on guest molecule encapsulation and TiO_2 hybridization to improve their semiconducting properties. Encapsulation with 4-aminopyridine significantly narrowed the band gap and increased

charge carrier concentration in both systems.

For Zn-MOF-74, interactions between 4-aminopyridine and Zn^{2+} ions improved molecular orbital alignment and minimized steric hindrance, resulting in moderate conductivity enhancement. Nevertheless, the RCT value remained relatively high at 5668 Ω, indicating limited intrinsic charge transport. Despite this limitation, hybridization with TiO_2 improved electron transport pathways and reduced recombination losses, leading to enhanced photovoltaic efficiency compared to the pristine system.

Mg-MOF-74 exhibited remarkable improvement upon encapsulation with 4-aminopyridine. The electron-donating nature of the guest molecule effectively compensated for the poor intrinsic conductivity of Mg^{2+}-based frameworks, reducing the RCT value to 14.5 Ω. This substantial reduction demonstrates the effectiveness of guest molecule engineering in overcoming conductivity limitations in Mg-based MOFs. Furthermore, TiO_2 incorporation enhanced charge transport and interfacial electron transfer, enabling Mg-MOF-74 to achieve significantly improved photovoltaic performance. Notably, the efficiencies of both Zn-MOF-74 and Mg-MOF-74 increased from the 10^{-4} % range to the 10^{-2} % range after encapsulation and TiO_2 hybridization, representing a considerable advancement in device performance.

Among all investigated guest molecules, 4-aminopyridine consistently exhibited the best performance across all MOF-74 systems. This superior behavior can be attributed to the presence of both the amino group and the pyridine ring, which promoted strong electronic interactions with the metal centers, enhanced charge injection, and stabilized the framework under operational conditions. Additionally, the integration of TiO_2 played a critical role in improving charge separation, reducing recombination losses, and establishing efficient electron transport pathways within the hybrid systems.

Conclusion

This investigation demonstrates that guest molecule incorporation into MOF-74 materials is an effective strategy for enhancing semiconducting and photovoltaic properties for sensitized solar cell applications. Encapsulation of guest molecules in Co-MOF-74, Ni-MOF-74, Zn-MOF-74, and Mg-MOF-74 significantly modifies their electronic and photovoltaic properties.

Overall, 4-aminopyridine combined with TiO_2 consistently yields the best performance across all MOFs by enhancing charge injection, transport, and reducing recombination, highlighting the importance of metal center selection, guest encapsulation, and hybridization strategies in improving MOF-based photovoltaic materials. This study demonstrates the potential of modified MOF-74 materials for sustainable, high-performance photovoltaic applications. The tunable properties of MOFs offer a versatile platform for developing advanced photoactive materials. Future work should focus on improving device stability, optimizing scalable fabrication, and exploring conductive guest molecules and hybrid nanocomposites.

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OPTIMIZATION OF THERMALLY TREATED BRICK CLAY FOR THE REMOVAL OF ANIONIC SURFACTANT FROM WASTEWATER AND ISOTHERM STUDIES



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Environmental pollution refers to the contamination of the natural environment by harmful substances or excessive energy, leading to adverse effects on ecosystems, human health, and biodiversity. Pollutants can be any substance (solid, liquid, or gas) or energy (such as radioactivity, heat, sound, or light). It is a global issue caused by various human activities and natural processes.

Water is essential to all forms of life and is polluted by different industrial and household activities through runoff and atmospheric deposition. Surfactants are the major ingredient type in various industrial and household products, acting as washing agents. Surfactant-based detergents are used to eliminate pathogenic organisms in hospitals, as major ingredients in pesticides, to disperse oil spillage at sea, extractant for the removal of organic pollutants. Surfactants are widely used in textiles, fibers, food, paints, polymers, cosmetics, pharmaceuticals, mining, oil recovery, and pulp-paper industries. Surfactant molecules contain both hydrophilic and hydrophobic parts. The hydrophobic part is a 10–20 long hydrocarbon chain, while the hydrophilic part may or may not ionize depending on the type of surfactant. Surfactants can be divided into four main types: anionic, cationic, zwitterionic, and nonionic. An anionic surfactant includes a hydrophilic, negatively charged head group, which can be carboxylate, sulfate, phosphate, or sulfonate, and a hydrophobic long chain of hydrocarbons.

At low concentrations, surfactant molecules exist in the monomer state. When the concentration increases, they reach the critical micelle concentration (CMC) and then begin to self-associate to form a new pseudo-phase called a micelle. At concentrations above the CMC, surfactants solubilize more hydrophobic organic compounds than they would dissolve in water alone.

Sodium dodecyl sulphate (SDS) is the most common anionic surfactant, which carries a negative charge. This can be commercially found in pallet or powder form. The pellet form is more soluble in water and less toxic than the powder form. SDS can be prepared by reacting dodecanal with sulfuric acid, and the resulting product is reacted with sodium hydroxide to form SDS. Another method of preparation of SDS is the neutralization of dodecane (dodecyl) sulfuric acid ester with sodium hydroxide. Figure 1 shows the structure of SDS and widely used detergent for laundry purposes and other cleaning applications.

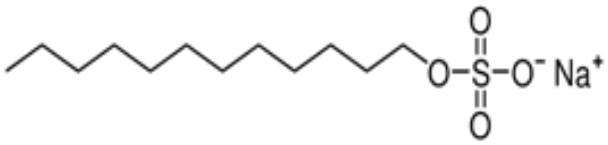


Figure 1: Structure of a SDS molecule

Surfactants are harmful to humans, fish, and plants. Due to their toxicity, they pose several health risks, including dermatitis. When present in certain concentrations, they can produce an unpleasant taste and odour. Surfactants can change ecosystems in both the short and long term. They lower the surface tension of water, allowing aqueous solutions to diffuse and penetrate easily. These properties of water negatively affect aquatic life by altering the properties of fish gills and the way fish ingest other substances.

Remediation is a process of preventing the release of pollutants to the environment and removing pollutants from contaminated water. The conventional methods of surfactant removal involve a process of coagulation and flocculation, chemical and electrochemical oxidation, membrane technology, chemical precipitation, photocatalytic degradation, adsorption, biological methods, and ultrasonic irradiation. Adsorption is recognized as an effective, efficient, popular, simple, and cost-effective technique for removing organic matter from wastewater.

Brick clay is a more effective, low-cost adsorbent for removing anionic surfactants from water compared to other treatment methods. Adsorption offers several advantages, especially for developing countries, as it is environmentally friendly and requires simple preparation. This study is focused on removing an anionic surfactant by adsorption on brick clay, a naturally abundant and eco-friendly adsorbent. Brick clay contains clay minerals such as kaolinite and illite, and it has layered structures with many pores and adsorption sites. The clay surface can adsorb negatively charged SDS through electrostatic interactions, hydrophobic interactions, and ion exchange. The brick clay surface can be easily modified by acid activation, thermal treatment, and surfactant modification and also has good mechanical strength.

Methodology

Samples of brick clay were obtained from a kiln, and they were crushed into pieces, followed by firing in an oven at a predetermined temperature for 4 h. They were then allowed to cool down to room temperature. The amount of SDS adsorbed/removed by burnt brick clay particles was determined using standard SDS solutions of concentration varying from 1.0×10^{-4} to 1.0×10^{-3} mol L^{-1} shaken with fired brick clay samples. For these determinations, mixtures of fired brick clay and SDS solution in a 2:25 (w/v) ratio were stirred at 150 rpm for 1.5 h and allowed to settle for 0.5 h, and a portion of 40.00 mL of each mixture was quickly separated, and 0.80 mL of Triton X-100 was added.

Burnt brick clay was characterized using Fourier transform infrared (FTIR) spectroscopy, X-ray fluorescence (XRF) spectrometry, scanning electron microscopy (SEM), thermal gravimetric analysis (TGA), turbidity measurements, and powder X-ray diffraction (PXRD). Isotherm studies were carried out by measuring the adsorption of 10 different initial concentrations of SDS solutions.

Results and Discussion

XRF spectra show that brick clay contains Fe and Ti as the main elements. Moreover, Fe and Ti have surface hydroxyl groups that can form complexes with heavy metals, anions, organic pollutants, and also Fe-based adsorbents often have a positive surface charge at natural pH, which attracts negatively charged SDS. The XRD pattern of the brick clay sample shows a combination of sharp and broad diffraction peaks, indicating that the material is polycrystalline with both well-defined mineral phases and partially amorphous components. The FTIR spectra after adsorption show several new peaks when compared with the initial spectrum, confirming the adsorption of SDS. Conversion of the highly rough and porous structure before adsorption to a smooth and fine structure after adsorption of SDS is clearly shown in SEM images. Surface titration curves of brick clay fired at 400°C indicate that the charge on the surface is positive.

As brick clay fired at 400°C shows the maximum adsorption capacity, it was used for further experiments. Adsorbent dosage of 80.0 g L^{-1} is suitable for further experiments because it gives nearly 85% SDS removal without pH optimization. The sample shaken for 1.5 h and settled for 0.5 h showed the maximum extent of removal of 94.9% without pH optimization. Moreover, fired brick clay showed 98% removal of SDS at pH 2, and an increase in the medium pH decreased the extent of removal.

The adsorption follows the Langmuir adsorption isotherm, with a higher regression coefficient and a high adsorption capacity of 86%.

Conclusion

Brick clay is an excellent adsorbent for SDS removal under the optimum conditions; a higher removal of over 99 % can be obtained under the optimum conditions of firing temperature of 400°C, adsorbent dosage of 80 g L^{-1}, shaking time of 1.5 h, settling time of 0.5 h, pH 2.0, and medium temperature of 40°C. Surface titration reveals that the point of zero charge of the adsorbent is at pH 9.6, and therefore the optimum pH ensures that the surface of brick clay is positively charged. SDS is a negatively charged species, leading to strong Coulombic attractions. Both SEM images before and after adsorption of SDS on brick clay support the adsorption. The minimum turbidity and the highest extent of removal by brick clay fired at 400°C confirm that it is the best firing temperature. Adsorption follows Type 1 IUPAC adsorption isotherms; further, it fits well with the Langmuir adsorption isotherm, with a higher R^2 value closer to 1, indicating monolayer adsorption with a chemisorption mechanism.

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SUSTAINABLE SYNTHESIS OF SiO_2 NANOSPHERES FROM *Dendrocalamus giganteus* LEAF-DERIVED SODIUM SILICATE: ENGINEERING TiO_2-Ag-SiO_2 NANOCOMPOSITES FOR EFFICIENT CIPROFLOXACIN DEGRADATION



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Water pollution by persistent organic pollutants (POPs), particularly pharmaceutical compounds, has emerged as a major global environmental challenge. Ciprofloxacin (CIP), a widely prescribed fluoroquinolone antibiotic, is a significant concern due to its high-water solubility, low biodegradability, and potential to contribute to antibiotic resistance in microbial communities. Advanced Oxidation Processes (AOPs) have garnered considerable attention as a powerful and effective solution for degrading POPs by generating highly reactive radicals, such as hydroxyl radicals ($OH^{\cdot}$), which can non-selectively mineralize a wide range of organic compounds into harmless by-products. Among AOPs, heterogeneous photocatalysis, which utilizes a semiconductor photocatalyst and a light source to drive redox reactions, stands out as a highly promising, environmentally friendly, and cost-effective technology.

TiO_2 is the most widely studied semiconductor photocatalyst owing to its high stability, non-toxicity, low cost, and excellent photocatalytic activity. However, its practical application is limited by two major drawbacks: its large band gap (>3.2 eV for the anatase phase), which restricts its activity to the ultraviolet (UV) region of the solar spectrum, and the rapid recombination of photogenerated electron-hole pairs, which reduces its overall quantum efficiency. In addition to enhancing performance, supporting the photocatalyst on a porous, high-surface-area matrix is crucial to prevent nanoparticle agglomeration, which can drastically reduce the number of available active sites. SiO_2 is an ideal support material due to its chemical inertness, high surface area, and tunable porosity.

This research, therefore, aimed to synthesize and characterize a novel TiO_2-Ag-SiO_2 nanocomposite photocatalyst, leveraging sustainably sourced silica. The work focuses on evaluating the influence of various synthesis parameters on the final material properties and comprehensively studying its photocatalytic efficiency for the degradation of CIP under different conditions. The findings are expected to contribute to the development of a highly efficient, stable, and cost-effective photocatalyst for advanced water treatment.

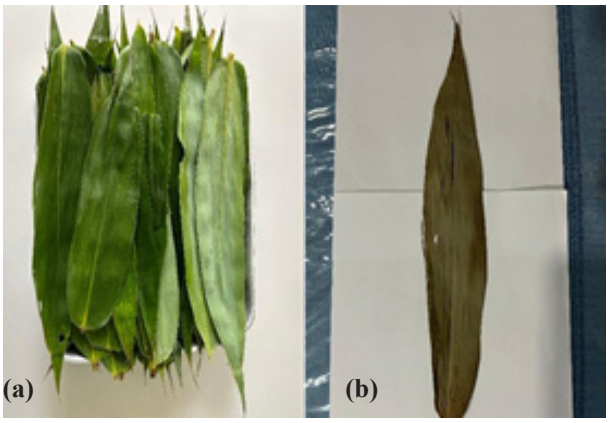


Figure 1: Mature (a) and dried (b) *Dendrocalamus giganteus* leaves

Methodology

The complete methodology involves the sustainable extraction of high-purity amorphous silica from *Dendrocalamus giganteus* leaves through calcination and alkaline treatment, followed by a modified sol-gel synthesis to produce ordered SiO_2 nanoparticles optimized by catalyst and pH adjustments. Concurrently, TiO_2 nanoparticles were synthesized via a sol-gel-assisted hydrothermal route and subsequently coated onto the SiO_2 spheres. Silver nanoparticles were then photochemically deposited on the TiO_2-SiO_2 composite under UV irradiation to finalize the TiO_2-Ag-SiO_2 photocatalyst. The material's efficiency was evaluated through the photocatalytic degradation of CIP, where parameters such as catalyst dosage, initial pollutant concentration, pH, and light wavelength (UV to visible) were systematically optimized. Comprehensive characterization including XRF, XRD, SEM, and FT-IR verified the elemental composition, amorphous or crystalline structure, morphology, and functional groups of the synthesized materials, while reusability was confirmed through desorption studies.

Results and Discussion

The initial characterization confirmed that dragon bamboo leaves are a potent source of silica, providing a yield of 17.7% (w/w) with a SiO_2 purity of 90.9%. SEM and ImageJ analysis of the synthesized silica nanospheres demonstrated that using citric acid as a catalyst at a neutral pH (~7) produced the smallest and most uniform particles (62±25 nm) compared to other acids and pH levels. FT-IR and XRD data further validated the formation of an amorphous silica framework, showing characteristic siloxane bonds and the typical "amorphous hump". In the photocatalytic studies, the TiO_2-Ag-SiO_2 nanocomposite demonstrated significantly higher efficiency in degrading ciprofloxacin compared to the undoped TiO_2-SiO_2 control. The screening process identified the citric acid-catalysed silica base as the most effective component for the composite. Optimization experiments determined that a 25 mg dosage was ideal for maximizing degradation. Furthermore, the inclusion of Ag nanoparticles was shown to be critical, as it enhanced visible light absorption via surface plasmon resonance and reduced the recombination of photogenerated charges. Operational tests confirmed that the composite remains highly effective across a range of pH values and light sources, proving to be a stable and reusable catalyst for advanced water treatment.

Conclusion

This research successfully established a sustainable and cost-effective protocol for synthesizing a high-performance TiO_2-Ag-SiO_2 nanocomposite photocatalyst. The study first demonstrated that *Dendrocalamus giganteus* leaves are an excellent biogenic source, yielding 17.7% (w/w) silica ash with a high SiO_2 purity of 90.9%. Through a controlled sol-gel process, it was determined that a neutral pH of 7 and a citric acid catalyst, combined with a CTAB and Triton X-100 template, provided the most effective morphological control, resulting in well-ordered spherical nanoparticles with an average size of 62 ±25 nm. The final TiO_2-Ag-SiO_2 nanocomposite exhibited superior photocatalytic performance in the degradation of CIP compared to the undoped TiO_2-SiO_2 control. Systematic optimization revealed that a catalyst dosage of 25 mg was ideal for treating a 15 mg L^{-1} CIP solution. The integration of silver nanoparticles was critical, as it enhanced the material's activity across a broad range of the solar spectrum, including effective degradation under visible light. Furthermore, desorption and stability studies confirmed that the nanocomposite remains robust and reusable over multiple cycles, making it a promising candidate for advanced wastewater treatment technologies.

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BIOASSAY GUIDED FRACTIONATION OF ANTI-HYPERGLYCEMIC COMPOUNDS EXTRACTED FROM *Cheilocostus speciosus* AND MODEL DEVELOPMENT FOR SUSTAINED RELEASE OF ANTI-HYPERGLYCEMIC COMPOUNDS USING ACARBOSE



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Diabetes mellitus (DM) is a prevalent metabolic disorder characterized by elevated blood glucose levels due to insufficient or absent insulin secretion by the pancreas. More than 425 million people worldwide are currently affected by diabetes mellitus (DM), with this number projected to rise to 629 million by 2045. The two most prominent general diabetes types are called type I and type II. Type I diabetes accounts for 5% - 10% of diabetes while Most of the population (90 %-95%) in the world has Type II diabetes. In Type II diabetes, the secretion of insulin is resisted. α-amylase and α-glucosidase enzymes cannot be inhibited by insulin with the lower level of insulin produced. Thus, blood glucose level rises than the range of healthy human beings.

In ayurvedic medicine, extracts of many plants were identified as therapeutic agents for type II DM. Among these medicinal plants, leaves of *Cheilocostus speciosus* (COS) are popular among Sri Lankans which are included in the main meals as a salad. COS has various medicinal properties and is used particularly in the treatment of asthma, fungal diseases, rheumatism, diabetes, and hepatoprotective disorders and is used as an ornamental plant. There is only handful of literature available related to the antidiabetic therapeutic effects of COS plant parts.

Currently, Acarbose and miglitol are considered competitive inhibitors of intestinal-glucosidases and reduce the postprandial digestion and absorption of starch and disaccharides. Therefore, these synthetic drugs are often used for Type II diabetic patients. One of the major drawbacks of current synthetic drugs is the need to use them multiple times per day. However, on the other hand, direct consumption of COS leaves for a longer period also poses risks of severe hypoglycemia. Montmorillonite (MMT) was selected as the drug delivery matrix due to its high cation exchange capacity, large specific surface area, biocompatibility, and ability to intercalate drug molecules between its layered structure. These properties enable controlled and sustained drug release, making MMT a promising carrier for minimizing rapid release and improving therapeutic efficacy. Therefore, this study aimed to scientifically evaluate the antidiabetic properties of COS leaf extract, perform bioassay-guided fractionation of antihyperglycemic compounds from the extract, and develop a model for the sustained drug release of these compounds using acarbose and MMT.

Methodology

This study focuses on the extraction of antihyperglycemic compounds and the isolation of active compounds using

bioassay guided fractionation. Therefore, initial solvent extraction of COS leaves was performed after Washing, air drying, oven drying and grinding using absolute ethanol as the solvent through sonication. This ethanol extract of the COS leaves was screened for α–amylase and α–glucosidase inhibition activities and bioactivity guided fractionation was carried out to isolate pure active compounds. The % Inhibition of α-amylase and α-glucosidase activity was calculated using the following formula;

$$\% \text{ inhibition} = \frac{[\text{Absorbance (control)} - \text{Absorbance Sample (Test} - \text{Blank)}] \times 100\%}{\text{Absorbance (control)}}$$

The concentration of extract that inhibits 50% c enzyme activity (IC_{50}) was measured using a series c ethanolic extract concentrations of COS leaves. IC_{50} wa detected by plotting % inhibition vs. $\log_{10}$ plant extrac concentration and calculated by logarithmic regressio analysis from mean inhibition values.

Ethanolic extract of COS leaves was identified as potential candidate with anti-hyperglycemic propertie and isolation of compounds responsible for the ant hyperglycemic effect was done with bioassay-guide fractionation (Figure 1)

Gravity column chromatography using Fluka 6074 silica gel upon dry loading was done with the hexan ethyl acetate: methanol solvent system, followed by thir layer chromatography (TLC) to find the best fractio with antihyperglycemic properties in terms of both α amylase inhibitory activity and α–glucosidase inhibitor activity.

Similar patterns with TLC were pooled and furthe purified using Size Exclusion Chromatography (SEC with a Sephadex LH-20 column as the stationary phas and chloroform as the mobile phase. For the fraction collected from SEC, TLC was done to identify th purified fractions. According to the TLC observation the fractions with only a single spot in TLC were use for further characterization using FTIR, ^{13}C NMR, and ^{1}H NMR analysis.

For the model development study, a 50 ppm acarbose solution was prepared, and the initial acarbose concentration was determined using UV method by plotting a calibration curve. Then 100 mL of pH-adjusted solutions were taken to separate beakers, and 1.0 g of MMT was added to each beaker. Then each beaker was stirred for 24 h at room temperature using a magnetic stirrer. Then 5 mL of supernatant was taken to another container, and 5 mL of 0.001 M $KMnO_4$/0.1 M NaOH solution was added to the same container. After proper mixing of the mixture, it was left aside for 15 minutes for the color development and then each mixture was scanned by UV-Vis Spectrophotometer within 300-750 nm to find the acarbose concentration after intercalation. Above mentioned intercalation procedure was carried out (three trials) with 50 ppm and 100 ppm initial acarbose solution at pH 6 (Optimum pH). Control experiments were conducted in triplicate using distilled water. The supernatants of the clay solutions were separated via centrifugation (4000 rpm, 30 min), and the isolated acarbose-intercalated MMT were dried at 40 ^{0}C for 24 h and characterized using FTIR and XRD. The *in-vitro* drug release study was done using the dialysis cell method over the period of 48 hours.

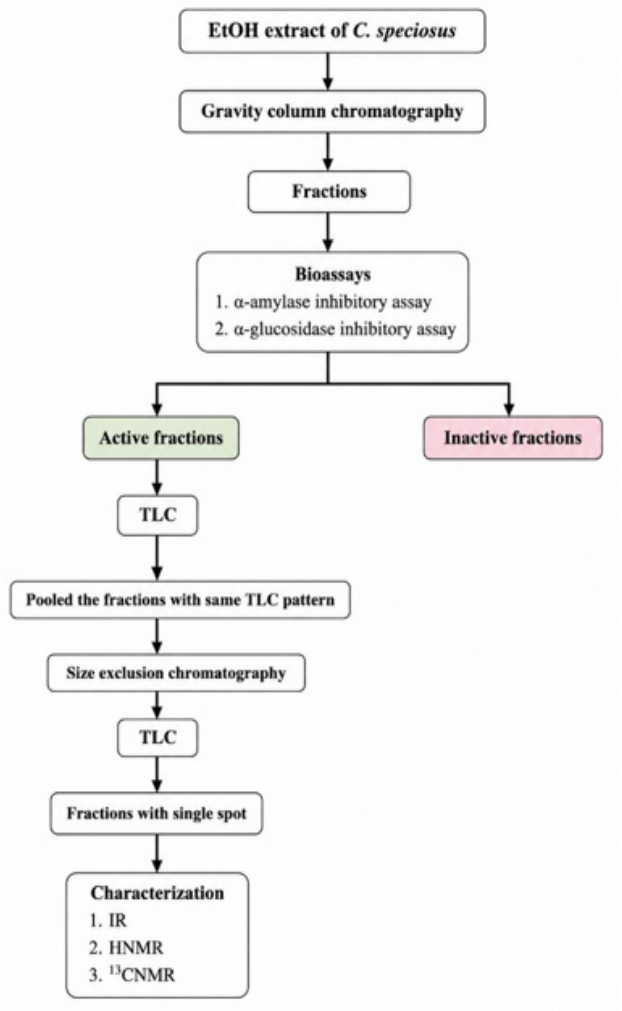


Figure 1: Flow chart for the activity-guided fractionation

Results and Discussion

According to the results obtained, the percent yield of ethanolic crude extract of COS leaves was calculated as 5.68 %. Active fractions obtained from the chromatographic separation of the ethanol extract of COS showed positive results for both α–amylase and α–glucosidase enzyme inhibitory activities. IC_{50} values of the ethanol extract of COS against α-amylase and α-glucosidase were 14.62 ppm and 21.20 ppm, respectively.

The quantities of isolated compounds were insufficient for HPLC analysis. Moreover, efforts to structurally identify

the active compounds were hindered by their limited quantities and the sensitivity limitations of the NMR instrument. Therefore, re-isolation of the active compounds using a larger amount of crude extract is necessary for comprehensive structural elucidation and characterization.

According to the acarbose intercalation study, the optimum intercalation was achieved at pH= 6. The varying of concentration results suggested that the intercalation of acarbose has increased from 2.18 (47.77%) mg g^{-1} to 5.14 (52.57%) mg g^{-1} with the increment in initial concentration of acarbose from 50 ppm to 100 ppm (Figure 2).

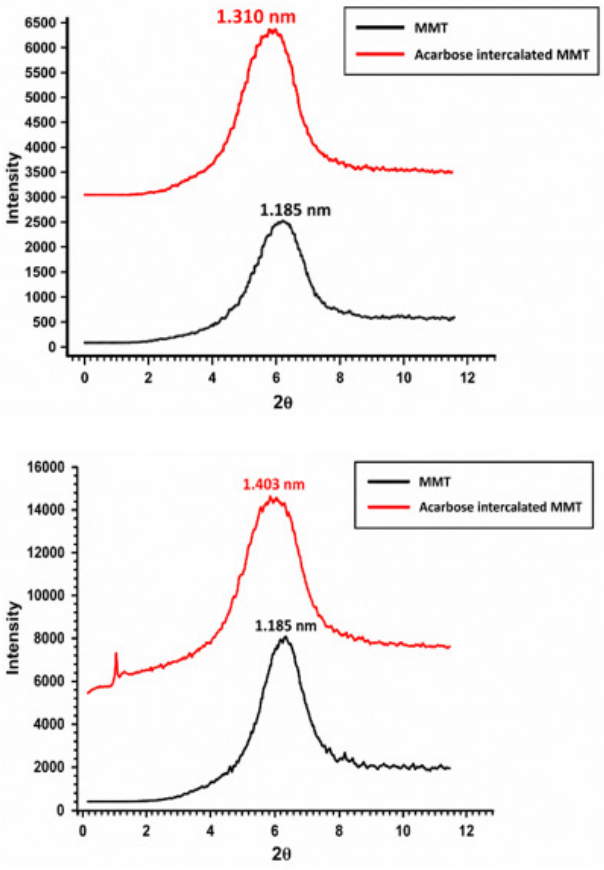


Figure 2: a) XRD patterns of intercalated Na-MMT at initial concentration 50 ppm, b) XRD patterns of intercalated Na-MMT at initial concentration 100 ppm

According to the results obtained from the drug release study, acarbose was gradually released in the first 8 h up to 45.66 % then slow release was observed afterwards in the simulated intestinal fluid (PBS 7.4). The maximum release of acarbose from MMT in intestinal fluids was observed to be 60.58 % and 3.09 mg/g of clay after 24 h. This is in accordance with the other reported drug delivery systems where 60 – 75% release was observed. The release of the drug from the matrix can be explained as an ion-exchange process between the intercalated drug and the alkali metal ions of the buffer.

A correlation coefficient (R^2) of 0.9767 was obtained for the pseudo-second-order kinetics model (Figure 3). The acarbose release at equilibrium shows a good fit with the pseudo-second-order model. Results suggest that the rate of the release process appears to be controlled by the chemical process according to the pseudo-second-order reaction mechanism, and the rate-limiting step may be a chemical adsorption involving valence forces through sharing or exchange of electrons between acarbose molecules and MMT.

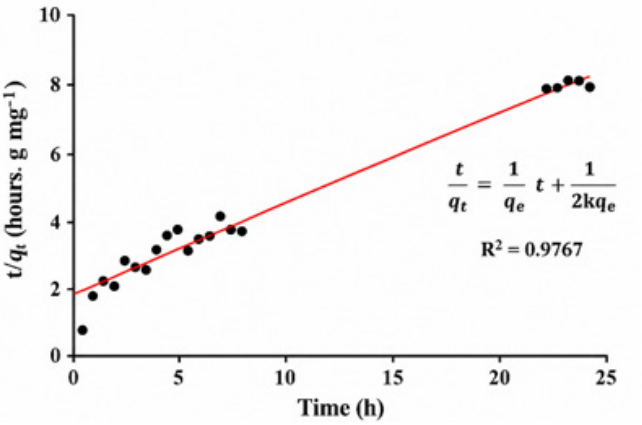


Figure 3: Pseudo-second-order kinetic model for the acarbose release study for 24 hours of time

Conclusion

The ethanol extract of *Cheilocostus speciosus* (COS) leaves exhibited significant α-amylase and α-glucosidase inhibitory activities (IC_{50}: 14.62 ppm and 21.20 ppm, respectively), demonstrating its potential as a natural source of antihyperglycemic agents. Bioassay-guided fractionation further identified several active fractions with up to 98% enzyme inhibition, highlighting the presence of potent bioactive compounds. As a preliminary model for sustained drug delivery, acarbose was successfully intercalated into (MMT). UV-Vis, FTIR, and XRD analyses confirmed successful intercalation under optimum conditions (pH 6), while in vitro release studies demonstrated a gradual release during the first 8 h followed by sustained release, confirming the suitability of MMT as a controlled-release carrier.

Overall, this study demonstrates the potential of *C. speciosus* as a promising source of natural antidiabetic compounds and highlights the feasibility of MMT-based sustained-release formulations. Further studies are required to isolate and characterize the active compounds from COS and evaluate their intercalation and controlled-release behavior to support the development of safer plant-based antidiabetic therapies.

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Edirisinghe, L., Rathnayake, S., Alakolanga, A., Senarathna, K., & Wijesekara, K. (2025). Bioassay guided fractionation of anti-hyperglycemic compounds extracted from *Cheilocostus speciosus*, and model development for sustained release of anti-hyperglycemic compounds using acarbose. *Sri Lankan Journal of Applied Sciences*, 3(2), 51–58. https://doi.org/10.4038/sljoas.v3i2.7

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POTENTIAL OF THE VERSATILE METAL-ORGANIC FRAMEWORK MIL-101(Fe) IN DRUG DELIVERY APPLICATIONS



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Metal-organic frameworks (MOFs) are a novel class of organic-inorganic hybrid materials. They are highly crystalline solids at room temperature, which are stable under many conditions, with ordered pore structures allowing them to be used for a variety of applications such as drug delivery, gas adsorption and separation, and catalysis. They are primarily composed of metal ions/ ion clusters joined together by coordinating organic ligands. This allows a virtually unlimited number of different MOFs to be synthesized simply by varying the component metal and ligand. MOFs are also easy to synthesize, and several different synthesis approaches are available, such as hydrothermal, solvothermal, microwave-assisted, chemical vapor deposition, refluxing, and ball milling. A few worthwhile mentions are the MIL, MOF, and ZIF families, with already proven practical applications. A large number of recent research works show the importance and popularity of these novel materials among chemists. An increasing number of research papers yearly show the usefulness of MOFs in developing drug delivery systems.

Drug delivery systems are mechanisms used to 'carry drugs' to desired locations within the body rather than to directly administer them. The idea behind developing these is to mitigate the numerous drawbacks of the direct administration of drugs, such as patient noncompliance caused by repeated doses, drug toxicity caused by high plasma concentrations, and wastage of drugs caused by poor bioavailability. These systems offer much better control over the release of the drug, facilitating targeted and/ or sustained release. Currently available drug delivery systems include polymeric nano/ micro particles, dendrimers, liposomes, foams, and hydrogels. Among other uses, MOFs are particularly interesting as drug delivery vehicles due to their inherent qualities suitable for drug carriers, such as high porosity, stability in biological environments, biocompatibility (depending on the components), and high surface area. A considerable number of previous works have shown promising loading capacities and controlled release capabilities for different MOFs. This research focused on MIL-101(Fe), one of the MIL (Material de Institut Lavoisier) family MOFs composed of iron centers interconnected by terephthalic acid ligands, forming huge pores and large pore windows. Its components are biocompatible, and it offers an immense surface area compared to other MOFs, showing great potential to be used as drug carriers. Its large pore openings (windows) facilitate the in and out movement of drug molecules of a wide range of molecular dimensions. This work demonstrated its ability to act as a drug carrier for the two highly demanded drugs, metformin and indomethacin, with different chemical properties, the former being hydrophilic and small, and the latter being hydrophobic and bulky.

Metformin is an antihyperglycemic drug given to counter type II diabetes mellitus. It is an over-the-counter and safe drug that is not known to cause any serious side effects. But it is poorly bioavailable, meaning that only about 55-60% of the drug is actually available for the body out of any given dose. This is significantly economically disadvantageous and also affects patient compliance due to having to take multiple doses to counter the low bioavailability. Indomethacin is a non-steroidal anti-inflammatory drug prescribed for relieving pain and other symptoms such as inflammation caused

by arthritis-related conditions. Contrary to metformin, it is highly bioavailable (100%) but causes severe side effects in various parts of the body, such as the central nervous system, gastrointestinal system, and skin. These side effects are caused by reaching high plasma concentrations resulting from fast absorption into the bloodstream. These issues can be negated by developing a delivery system to release them in a controlled manner, so that the drug concentration in the plasma is kept within the window of minimum therapeutic concentration and the minimum toxic concentration. Since both are highly demanded drugs as well, their selection for the current work was important.

Methodology

Firstly, MIL-101(Fe) was synthesized via a pre-existing solvothermal synthesis route, but with a couple of important modifications to yield a high-purity product, which is important for drug delivery applications in two major aspects. Firstly, a high-purity MOF will provide a higher capacity for drug encapsulation. Secondly, the absence of impurities, such as toxic solvent molecules, ensures the absence of cytotoxicity. Therefore, the procedure involved a rigorous purification protocol to ensure no raw materials, including toxic solvent molecules, are left with the product. Several characterization techniques were employed to verify the crystalline structure and the expected high purity of the product (PXRD, FTIR, SEM, and TGA). MOF particles were then loaded with metformin and indomethacin separately by suspending them in ethanolic solutions of each drug over a period of 24 hours (predetermined ideal loading duration). The use of absolute ethanol as the solvent is justified as both drugs (despite one being hydrophilic and the other being hydrophobic) are soluble in it. The drug-loaded MOF particles were characterized again using FTIR, SEM, TGA, and UV-vis spectroscopy to confirm the successful loading. Drug release studies were conducted by suspending loaded MOF particles in PBS and HCl media for 48 hours, mimicking physiological conditions within the digestive system, such that PBS approximates the intestinal environment and HCl approximates the stomach environment. UV-vis spectroscopy was used throughout to determine loading capacities and to build release profiles for both drugs.

Results and Discussion

Initially, hydrothermal synthesis was attempted in the hope of avoiding toxic solvents, but it yielded a mixture of recrystallized terephthalic acid and hematite as the products rather than MIL-101(Fe). Following solvothermal trials yielded the proper product with excellent crystallinity, whose structure was confirmed with PXRD. In addition to the presence of MIL-101(Fe) peaks, the absence of peaks corresponding to terephthalic acid confirmed the expected high purity (the absence of recrystallized terephthalic acid). SEM images confirmed the typical octahedral crystal morphology and revealed the particle size to be in the range of ~400 nm - ~800 nm. The SEM did not show any spindle-shaped crystals, confirming the absence of recrystallized terephthalic acid.

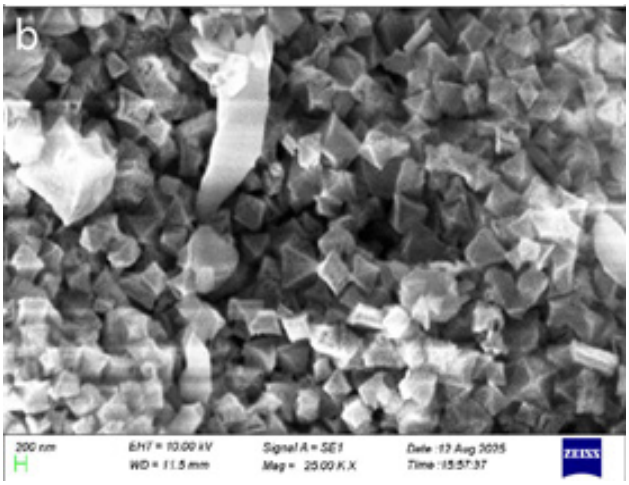


Figure 1: SEM image of MIL-101(Fe)

FTIR also confirmed the high purity by not showing bands related to free carboxylic acids (terephthalic acid), free -OH groups (ethanol and water), and DMF, while showing bands related to the expected product. TGA demonstrated excellent thermal stability well beyond 300 °C, which is well within the temperature ranges related to drug delivery applications. Further, the MOF showed excellent stability in absolute ethanol during the testing period of 48 hours, which is vital in order to use ethanol as the loading medium for both drugs.

UV-vis spectroscopy, FTIR, and TGA confirmed the successful loading of both drugs into the MIL-101(Fe) particles. UV-vis spectroscopy also revealed gradual uptake of the drugs over the 24 hours, confirming actual adsorption within the pores rather than surface sorption. Significant loading capacities of 0.19 mg Met/ mg MOF for metformin and 0.27 mg Indo/ mg MOF for indomethacin were observed as the averages of multiple loading experiments. This is equal to a loading efficiency of 19% for metformin and 27% for indomethacin, considering the used drug masses. The differences in loading capacities may be explained by considering the molecular structure of the two drugs. Metformin's structure is composed of primary, secondary, and tertiary amine groups as the only functional groups. Hence, it can form coordination bonds with the iron metal centers within the MOF pores, using the lone pair electrons on the nitrogen atoms (except tertiary nitrogen). Indomethacin structure, in contrast, contains a carboxylic acid group, which can form stronger coordination bonds with the iron metal centers than the nitrogen atoms in metformin. Furthermore, the presence of aromatic rings on the indomethacin structure may allow pi-pi stacking opportunities with the aromatic rings of the component terephthalic acid molecules of

MIL-101(Fe). This possibility of much stronger interactions for indomethacin explains why it shows a higher loading capacity than metformin in MIL-101(Fe).

In vitro drug release studies resulted in impressive observations. Both drugs exhibited slow and steady release in both media (PBS and HCl) without initial surge releases. This also confirms actual loading of the drugs into the pores rather than surface sorption (surface sorption should have resulted in an initial burst release). Met@MIL-101(Fe) (metformin-loaded MOF particles) showed only ~14% release in PBS within the first hour, which is a significantly slower release rate. Comparatively, the popular commercially available German-made drug Glucophage® XR releases 30% of metformin within the first hour, according to literature. Indomethacin also showed significantly slower release of ~10% within the first hour. Comparatively, previous work by others using different drug carriers resulted in much faster release rates, with initial burst effects as well. For example, a slow-release formulation of indomethacin called F5 by a team of scientists led by A. Abirami showed ~19% release within the first hour.

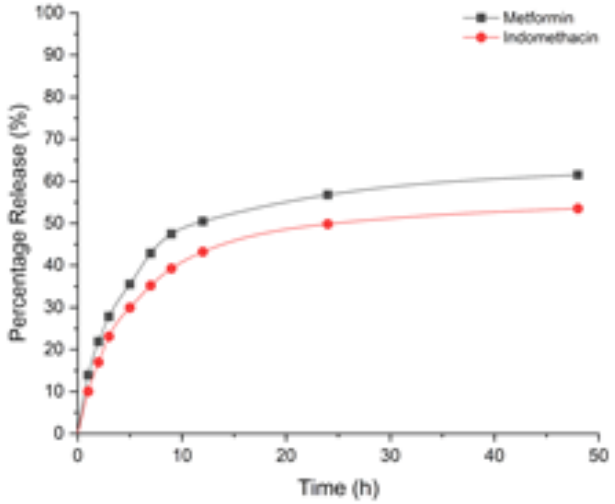


Figure 2: Release profiles of metformin & indomethacin in phosphate-buffered saline

A comparative study of the drug release profiles revealed a few key findings. MIL-101(Fe) was able to load both drugs effectively, despite one being hydrophilic and the other being hydrophobic. This shows the versatility of this particular MOF in acting as a carrier for both hydrophilic and hydrophobic drugs (further research with more drugs is required to confirm this). Metformin showed slightly higher release in HCl than in PBS, probably due to metformin being inherently basic, showing higher affinity to an acidic environment. Contrastingly, indomethacin showed slower release in HCl than in PBS, which could be due to indomethacin being acidic in nature, showing lower affinity to an acidic environment. In fact, indomethacin release in HCl was significantly low. This confirms the ability of MIL-101(Fe) to act as a pH-controlled release carrier for inherently acidic drugs (further research with more acidic drugs is required to confirm this). Furthermore, since only *in vitro* studies were performed and only two drugs were used, more studies are required before attempting clinical trials and to further explore the capability of MIL-101(Fe) in designing drug delivery systems. Future work may involve extending the work to test more drugs with different properties to fully understand the potential of MIL-101(Fe) in drug delivery. Moreover, post synthetic modifications, such as the application of a polymeric coating, might further extend the release.

Conclusion

The implemented synthesis protocol and the purification protocol yield highly crystalline MIL-101(Fe) particles with very high purity, ideal for drug delivery applications. It allows loading of metformin and indomethacin into its pores, offering high loading capacities. It allows the controlled release of metformin and indomethacin, providing extended-release capability for both drugs and targeted release capability for indomethacin.

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BALANGODA CALCITE DEPOSITS OF SRI LANKA: A RECORD OF CRUSTAL CARBONATE MELTING AT THE HIGHLAND-VIJAYAN BOUNDARY



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Rare examples of carbonate melting preserved in the continental crust offer important insights into deep Earth processes, crustal carbon mobility, and the behaviour of carbonate rocks under extreme metamorphic conditions. The Balangoda calcite bodies (CBs), located near the boundary between Sri Lanka's Highland Complex (HC) and Vijayan Complex (VC), represent one of the most unusual and best-preserved calcite-rich occurrences reported from high-grade metamorphic terrains.

These coarse-grained, monomineralic CBs occur as discontinuous bands and isolated pockets within marble-bearing metamorphic rocks, and they differ markedly from ordinary calcite occurrences reported worldwide. Despite several previous investigations, their origin has remained controversial, with interpretations ranging from hydrothermal vein formation to carbonatite-like magmatic emplacement.

The CBs occur within a region that underwent granulite-facies to ultra-high-temperature (UHT) metamorphism during the Neoproterozoic- Cambrian Pan-African tectono-metamorphic event. Previous studies indicate that rocks within the HC were subjected to temperatures of approximately 800-900^{o}C under deep-crustal conditions. Such environments raise important scientific questions about carbonate stability, carbonate melting, and carbon mobility within continental collision zones. Therefore, the primary objective of this research was to investigate the petrogenesis of the CBs using an integrated, multidisciplinary approach encompassing field geology, petrography, mineralogy, geochemistry, and stable isotope analyses. This study further aimed to distinguish the Balangoda CBs from hydrothermal carbonate systems and mantle-derived carbonatites and to evaluate whether these deposits represent products of crustal carbonate anatexis preserved within Sri Lanka's Precambrian crust.

Geological Significance:

The Balangoda CBs provide a rare example of crustal carbonate melting preserved within a high-grade metamorphic terrain. Their occurrence along the HC-VC boundary offers important insights into carbonate stability, fluid-assisted melting, and carbon mobility during deep crustal metamorphism. The study further demonstrates that crustal carbonate melts can develop textures and geochemical signatures distinct from both hydrothermal calcites and mantle-derived carbonatites, contributing to a broader understanding of deep carbon cycling and carbonate anatexis in continental collision zones.

Methodology

Fieldwork involved detailed geological mapping and sampling across multiple exposures in the Balangoda area, focusing on the relationships between CBs, host marbles, and associated enclaves. Samples were systematically collected to represent the diversity of calcite occurrences, including different colour varieties, host dolomitic marbles, and enclaves. Petrographic analysis examined textural relationships, mineral assemblages, and microstructural features. X-ray diffraction (XRD) confirmed mineralogical composition and purity. For geochemical characterization, major, minor, and trace element concentrations were determined using wavelength-dispersive X-ray fluorescence (WD-XRF) and inductively coupled plasma mass spectrometry (ICP-MS) at the Institute of Geology and Geophysics, Chinese Academy of Sciences (IGG-CAS). Rare earth element (REE) patterns were systematically compared with carbonate occurrences of different origins from similar geological terrains. Stable carbon and oxygen isotope analyses ($\delta^{13}C$ and $\delta^{18}O$) distinguished between mantle, crustal, and hydrothermal-derived carbonate sources.

Results and Discussion

Field observations revealed that the CBs commonly display large-scale colour banding in white, green, yellow, blue, and rose hues, with individual bands ranging from centimetres to metres in thickness. One of the most diagnostic features observed in the field is the presence of variably sized mafic and calc-silicate enclaves enclosed within the calcitic matrix (Figure 1). Many enclaves exhibit rotation, fragmentation, stretching, and flow-like alignment, indicating mechanical interaction with a mobile low-viscosity medium during emplacement. In several exposures, the calcite bands and enclaves are aligned parallel to the foliation of the host marble, suggesting subsequent deformation following emplacement. The close association between the CBs and mafic bands further indicates that lithological boundaries acted as structurally weak zones facilitating melt migration.

Petrographic investigations confirmed that the CBs are predominantly monomineralic and composed of coarse-grained calcite exceeding 98% purity, with minor accessory minerals including apatite, diopside, and graphite. The calcite grains are generally equigranular and display straight to slightly curved grain boundaries characteristic of high-temperature recrystallization. In some samples, localized disequilibrium textures and partial mineral replacement features occur near enclave margins and contact zones, suggesting melt-rock interaction during carbonate melt migration. Importantly, typical hydrothermal vein textures, such as crack-seal fabrics, comb structures, and open-space-filling textures, were not observed. Instead, the textural characteristics indicate crystallization from a carbonate melt generated under high-temperature metamorphic conditions. Geochemical analyses revealed that the CBs are enriched in large-ion lithophile elements and rare earth elements (REEs) relative to the surrounding marbles, although their overall REE abundances remain lower than those commonly reported from mantle-derived carbonatites. Total REE concentrations range from 6.24 to 268.29 ppm and exhibit light REE enrichment relative to heavy REEs. Fractionation patterns, including $(La/Yb)_N$, $(Ce/Yb)_N$, and $(Pr/Yb)_N$ ratios together with Eu anomalies, closely resemble crustal-derived carbonate melts documented from the Himalayan syntaxis, Grenville Province, and Turkey. These geochemical signatures differ significantly from those of both ordinary marbles and mantle-derived carbonatites, indicating a distinct crustal melt-related origin.



Figure 1: Photograph of very coarse-grained, coloured calcite bands exposed in a calcite quarry site in Rajawaka, Balangoda

Stable isotope compositions provided additional constraints on the source and evolution of the CBs. The $\delta^{13}C$ values range from -0.85‰ to 0.31‰, whereas $\delta^{18}O$ values range from 21.7‰ to 23.64‰. These isotopic compositions differ from those of host marbles, hydrothermal calcites, and mantle-derived carbonatites, but closely resemble crustal-derived carbonate melts reported from other high-grade metamorphic terrains worldwide. The slight depletion of carbon isotopes relative to the host marbles likely reflects isotopic fractionation associated with carbonate melting and subsequent crystallization.

Proposed petrogenetic model and geological conditions:

The line of evidence suggests that the HC-VC boundary provided favourable tectonic and metamorphic conditions for crustal carbonate anatexis. During thrusting of the HC over the VC, devolatilization reactions likely released CO_2-H_2O-rich fluids into the surrounding crust. Simultaneously, granulite-facies to ultra-high-temperature metamorphism subjected the rocks to temperatures of approximately 800-900 ^oC under deep crustal conditions. Experimental

studies demonstrate that aqueous fluids reduce calcite and dolomite melting temperatures by up to 600 °C. The influx of fluids would promote partial melting within marbles. Initial melting likely occurred at grain boundaries and triple junctions, generating localized calcitic melt pockets within the marble sequence. As melt fractions increased, an interconnected low-viscosity carbonate melt network developed and migrated through fractures and compositional boundaries between marbles and mafic bands (Figure 2). During melt migration, the existing mafic band fragmented, and the fragments became entrained within the flowing melt, producing the rotated and fragmented enclaves preserved within the CBs. Subsequent cooling and recrystallization of the carbonate melt formed coarse-grained monomineralic calcite bodies, while later deformation likely resulted in the parallel alignment of calcite bands and enclaves with the foliation of the host marble. This integrated petrogenetic model successfully explains the observed field relationships, melt-flow structures, petrographic textures, geochemical signatures, isotopic characteristics, and structural features of the Balangoda CBs, supporting their formation through fluid-assisted crustal carbonate melting during high-temperature metamorphism along the HC-VC boundary.

Conclusion

This study provides the first integrated evidence that the CBs formed through crustal carbonate anatexis along the HC-VC boundary of Sri Lanka during the thrusting of the HC over the VC. Field relationships, melt-flow textures, rotated enclaves, petrographic characteristics, geochemical signatures, and stable isotope compositions collectively demonstrate a melt-related origin distinct from both hydrothermal carbonate systems and mantle-derived carbonatites. The proposed petrogenetic model highlights the role of high-temperature metamorphism, fluid-assisted melting, and tectonic deformation in generating and mobilizing carbonate melts within the deep continental crust. The Balangoda calcite occurrences represent one of the best-preserved examples of crustal carbonate melting documented from a high-grade metamorphic terrain and provides important insights into carbonate stability, crustal carbon cycling, and deep Earth processes associated with continental collision zones. This research, therefore, contributes not only to understanding Sri Lanka's Precambrian geology but also to broader global discussions regarding crustal carbonate melting and carbon mobility within the continental crust.

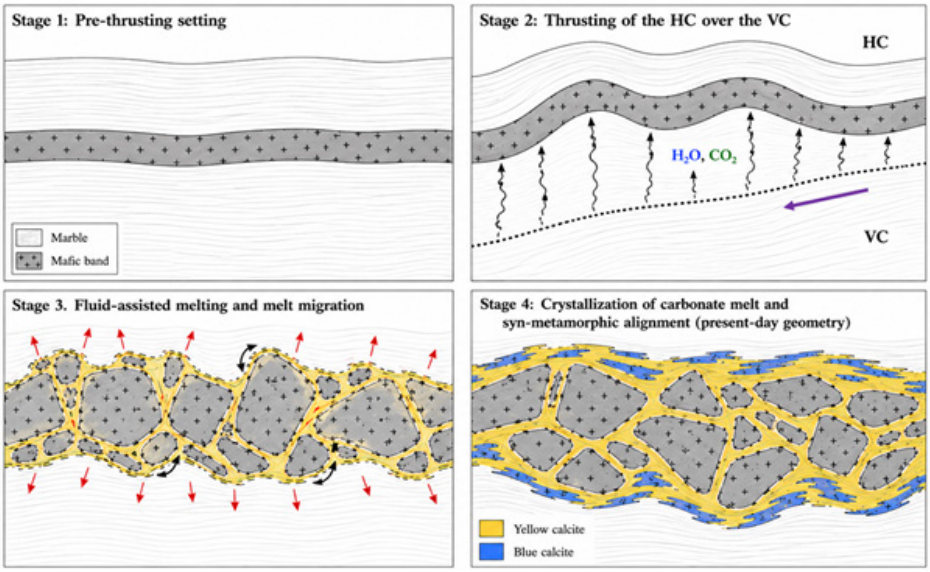


Figure 2: Conceptual model of fluid-assisted crustal carbonate melting; ***Stage 1***: Prior to deformation, the mafic band was parallel to the regional foliation and remained largely intact within the marble sequence. ***Stage 2:*** Low-angle thrusting of the HC over the VC generated CO_2-H_2O-rich fluids through decarbonation and dehydration reactions along the thrust zone. These fluids migrated upward through weak pathways and accumulated within marble, creating favourable conditions for fluid-assisted carbonate melting. ***Stage 3:*** Infiltration of fluids promoted fluid-assisted partial melting of the marble specifically adjacent to the mafic band. Carbonate melt was generated and migrated along structurally weak pathways, particularly along mafic band-marble contacts. Progressive melt migration caused fracturing, disaggregation, and separation of the mafic band into blocky enclaves. Some enclaves underwent rotation and limited transport within the flowing carbonate melt during syn-metamorphic deformation. ***Stage 4:*** Carbonate melt crystallized to form calcite-rich bodies surrounding the disaggregated mafic enclaves. Yellow calcite developed adjacent to enclave margins, whereas blue calcite formed as discontinuous bands and lenses within the calcite body. Continued syn-metamorphic deformation resulted in rotation, alignment, and elongation of the enclaves and calcite bands parallel to the regional foliation, producing the present-day field geometry.

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GEOCHEMICAL AND MINERALOGICAL ASSESSMENT OF PHOSPHATE ORES AT EPPAWALA, SRI LANKA: IMPLICATIONS FOR RESOURCE OPTIMIZATION AND VALUE ADDITION



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Rare earth elements (REEs) are critical raw materials for modern technologies. Their unique magnetic, optical, and catalytic properties make them essential for wind turbines, electric vehicles, smartphones, advanced electronics, and many green-energy applications. However, global REE supply remains vulnerable to geopolitical constraints and the rapid depletion of high-grade deposits.

This has increased interest in alternative REE resources, including phosphate ores formed through the weathering of carbonatite rocks. In Sri Lanka, the Eppawala phosphate deposit represents one such promising resource. Despite its economic importance, comprehensive studies on the occurrence and behavior of REEs in the weathered phosphate ores remain limited. Furthermore, the existing phosphate processing plant, which has operated for more than 35 years, has focused primarily on fertilizer production, with little attention given to the recovery of other valuable components. Consequently, potentially valuable REEs may be lost during processing.

This multidisciplinary MPhil study investigated the weathering processes that formed the Eppawala phosphate ores, evaluated the distribution and enrichment of REEs to assess their economic potential, developed a processing route for REE recovery, and explored the production of value-added nanomaterials from processing by-products.

Methodology

Weathered phosphate ore samples were collected from weathering profiles exposed at the Main Quarry (EM) and Southern Quarry (ES) of the Eppawala deposit. Field observations of texture, mineralogy, color, porosity, and compaction were used to identify and classify weathering zones.

Representative samples were analyzed using standard geochemical and mineralogical techniques to determine major, minor, and trace element compositions and to identify mineral phases. Based on the ore characteristics, a processing route was developed to recover REEs.

The phosphate-rich by-products generated during REE extraction were subsequently utilized to synthesize nano-fluorapatite (nano-FAp) through chemical precipitation technique.

The recovered REE products and synthesized nano-FAp were characterized using complementary analytical techniques to evaluate their mineralogical, morphological, and chemical properties.

Results and Discussion

Field observations indicate that the phosphate ores evolved through complex, cyclic weathering in a tropical karstic environment. The Southern Quarry (ES) exhibits relatively thin, homogeneous, and minimally karstified profiles with distinct weathering zones and shallow parent-rock exposures. In contrast, the Main Quarry (EM) displays highly mature profiles characterized by intense karstification, poorly defined zones, and greater structural heterogeneity.

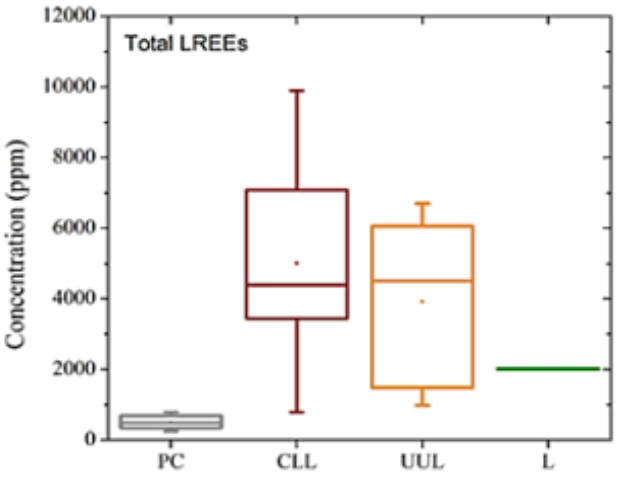


Figure 1: Total light rare earth elements (LREEs; La to Eu) in different weathering zones of the EM weathered profile. PC-parent carbonatite, CLL- consolidated lower leached zone, UUL-unconsolidated upper leached zone, L-lateritic zone

Most exposures belong to a leached zone consisting of a CLL and an UUL. The CLL contains weather-resistant primary minerals (apatite, magnetite, and ilmenite) embedded in a hard secondary matrix, while the UUL comprises residual apatite crystals in a loose soil matrix rich in fine-grained secondary phosphates and iron oxides. Only limited lateritic and saprolite zones were observed. The interplay of mineral dissolution, elemental leaching, precipitation, compaction, and cementation produced the pronounced heterogeneity across the profiles.

Despite physical and structural differences, both quarries show similar geochemical evolution and supergene mineral assemblages. A key finding was the anomalous enrichment in alumina and silica, which was significantly higher than typical weathered carbonatite profiles. This is evidenced by the presence of aluminophosphate minerals (gorceixite, florencite, and goyazite) and aluminosilicates, including gobbinsite and heulandite, which are reported here for the first time from the Eppawala deposit. These observations suggest incorporation of material from adjacent granitic country rocks.

Weathering processes concentrated total REEs up to tenfold relative to the parent carbonatite (maximum 10,932 ppm), with the highest enrichment in the CLL zone, moderate levels in the UUL, and the lowest in the lateritic zone (Figure 1). Chondrite-normalized REE patterns are remarkably consistent across profiles, indicating that REE behavior is controlled by apatite weathering and selective accumulation in secondary phosphates and aluminophosphates, rather than by discrete REE minerals such as monazite. Bulk mineralogy and statistical correlations support this interpretation.

The CLL zone represents the most prospective horizon for REE exploration and extraction. Because REEs are structurally bound within apatite and secondary phosphates (rather than occurring as easily processable phases like bastnasite or monazite), recovery required a tailored combination of physical beneficiation and chemical leaching under controlled pH conditions. This process successfully upgraded the REE grade from 0.33 wt% to 4.95 wt% as a mixed REE product, with potential for further recovery using advanced separation techniques.

Phosphate- and fluoride-rich by-products from REE extraction were used as precursors for nano-fluorapatite (nano-FAp) synthesis. Characterization confirmed the formation of highly crystalline, phase-pure fluorapatite with hexagonal morphology and an average particle size of 100 nm. The presence of fluoride ions is inherent to the ore favored FAp formation over hydroxyapatite. These nanomaterials show promising potential for preventive dentistry and tissue engineering, pending further evaluation of antibacterial and biocompatible properties.

Conclusion

This study demonstrates that the Eppawala phosphate deposit formed through prolonged tropical weathering of carbonatite rocks, resulting in the development of diverse secondary minerals and significant enrichment of valuable elements, particularly phosphorus and REEs. The study shows that REEs are hosted primarily within apatite and secondary phosphate minerals rather than occurring as discrete REE-bearing minerals. Despite this mineralogical complexity, a processing route was successfully developed that increased the REE grade from 0.33% to 4.95%, demonstrating the feasibility of recovering these critical raw materials. In addition,

phosphate- and fluoride-rich by-products generated during REE extraction were converted into high-quality nano-fluorapatite (nano-FAp), a value-added nanomaterial with potential applications in dentistry and tissue engineering.

Overall, the findings reveal that the Eppawala phosphate deposit possesses substantially greater economic potential than previously recognized. The integrated recovery of REEs, together with the conversion of processing by-products into useful nanomaterials, highlights a pathway toward more sustainable and value-added utilization of Sri Lanka's phosphate resources while contributing to the growing global demand for materials essential to green technologies.

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GEO-ENVIRONMENTAL IMPLICATIONS OF THE PROGRESSION OF CHRONIC KIDNEY DISEASE OF UNKNOWN ETIOLOGY (CKDu) IN WILGAMUWA REGION, SRI LANKA



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Increasing urbanization appears to be the dominant factor in the global spread of noncommunicable diseases, largely due to the escalation of sedentary lifestyles among humans. Among known non-communicable diseases, chronic kidney disease (CKD) is the 12th leading cause of death worldwide and leads to progressive, irreversible deterioration of kidney function due to various causes. CKD is introduced as reduced glomerular filtration rate, increased urinary albumin excretion, or both, with the prevalence rate of 8–16% globally. Worldwide, diabetes mellitus, long-standing hypertension, and obesity are the most common causes of chronic kidney disease, but in some countries of Asia and sub-Saharan Africa, other causes, such as glomerulonephritis and unknown causes, are more common. However, the prevalence rate of CKD varies by gender, with women being more susceptible to CKD than men, and more common in older populations than in younger generations.

In Sri Lanka, in the absence of communal risk factors associated with CKD prevalence, a special type of CKD with unknown origin has been become a major burden in the dry zone among the rural farming communities mainly affects male farmers between the ages of 30 and 60, over three decades. However, CKDu progresses silently without obvious symptoms until severe kidney damage occurs. Therefore, CKDu is believed to be environmentally induced disease. Hence, environmental factors such as contaminated drinking water, prolonged exposure to agrochemicals, excessive heat, bacterial toxins, viral infections, and the use of substandard Aluminium utensils are often suspected of causatives.

Numerous case-control studies on CKDu have been conducted in Sri Lanka for over 30 years. Many animal models with comparable environmental exposures have also been used to identify the possible environmental factors contributing to CKDu. However, the ecological impacts of CKDu at-risk communities in endemic areas have not yet been the subject of studies. Since CKDu progresses slowly and can affect younger people, with symptoms not manifesting until later in life. Thus, a better understanding of the CKDu pandemic can be achieved by identifying viable environmental risk factors associated with the CKDu-at-risk population and addressing the necessary remedial measures as early as possible. Therefore, this study aims to identify the possible environmental and biological factors controlling the prevalence rate of chronic kidney disease of unknown origin (CKDu) in at-risk communities in CKDu-endemic regions comparing CKDu Low-prevalence and non-endemic regions, which was a research gap during the investigation period.

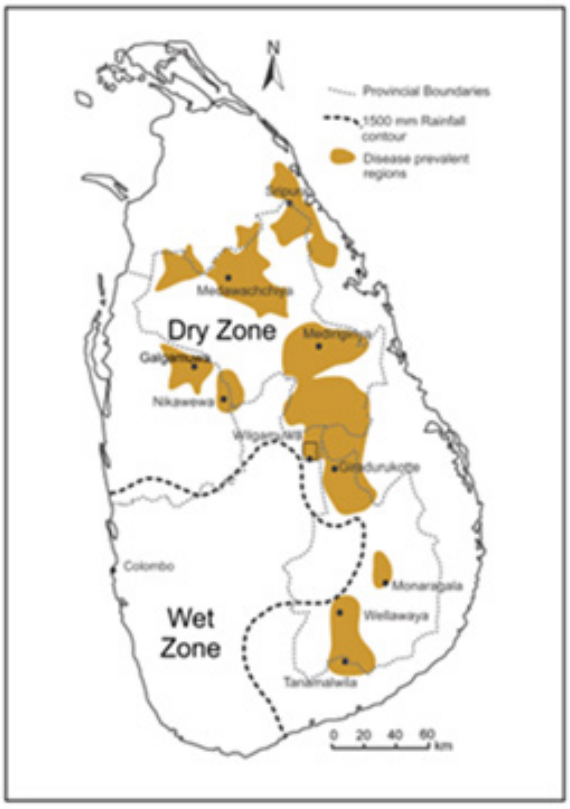


Figure 1: CKDu prevalence regions of Sri Lanka

Methodology

Groundwater samples were collected from 92 wells in the CKDu-endemic (Wilgamuwa) region, 28 wells in the low-prevalence (Hassalaka) area, 20 wells in the CKDu-free wet zone (Dodamwala), and 5 surface water reservoirs in Wilgamuwa. Field parameters (pH, EC, temperature, total alkalinity) were measured in situ. Laboratory analyses encompassed major anion and cation concentrations, trace elements (including As, Cd, Pb), stable isotope compositions (δ^2H and $\delta^{18}O$), microbiological screening (including E. coli) with DNA sequencing for microbial community profiling. Further, groundwater origin and fate were analyzed using necessary geo-chemical evaluation diagrams. Water Quality Index (WQI) and Hazard Quotient (HQ) values for toxic elements were calculated for comparative health risk assessment across all study regions. In addition, seasonal sampling was conducted across pre- and post-monsoon periods to capture temporal variability.

Results and Discussion

Groundwater in the CKDu region had higher electrical conductivity (median = 226 µS/cm) and lower trace metal contents than in the wet zone. In contrast, groundwater isotope values (δ^2H and $\delta^{18}O$) in CKDu-endemic and low-prevalence areas are primarily derived from the northeast monsoon. A Ca-HCO_3- type groundwater is more common in the study regions. Interestingly, the average Si^{4+} concentration was higher in the CKDu prevalence area (47 mg/L) than in the disease-free area (8.2 mg/L) and the low-prevalence area (20.5 mg/L) in the dry zone, with no significant difference in lithology across the regions. Furthermore, 68% and 36% of wells used by CKDu-vulnerable and low-prevalence communities were categorised as "hard" and "very hard," respectively. However, only 10% of the wells in the wet zone are classified as hard or very hard. The fluoride content is significantly higher ($p < 0.05$) in the CKDu area (mean: 0.62 mg/L) compared to wells in the low-prevalence zone (mean: 0.15 mg/L) and the wet zone (mean: 0.03 mg/L). The Water Quality Index (WQI) of the CKDu prevalence region showed a strong positive correlation with the fluoride content ($r = +0.995$).

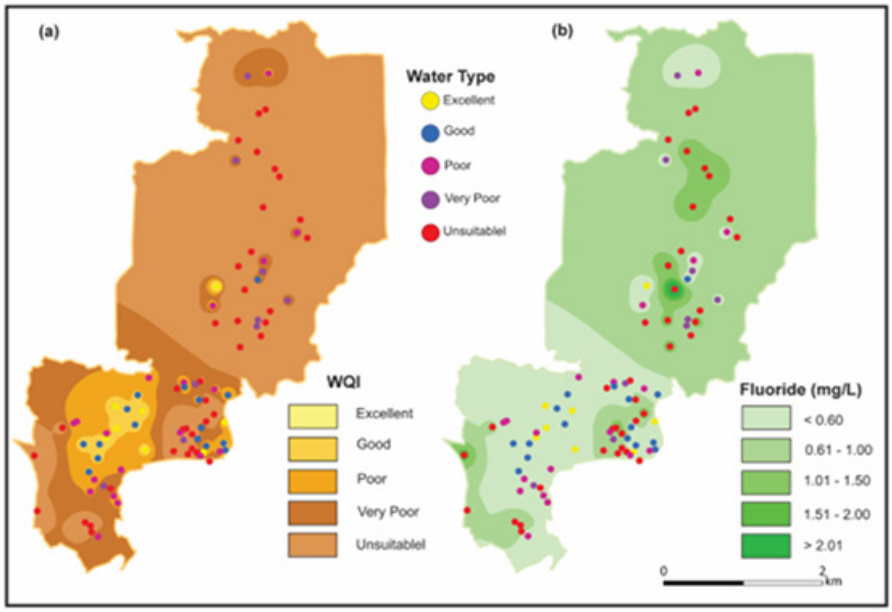


Figure 2: Spatial distribution of (a) water quality index (WQI) and (b) fluoride in groundwater in the CKDu endemic region

More than 12% of children and 85% of adults and children were categorised as being at moderate risk for F^- and SiO_2 based on Hazard Quotient (HQ) values. Nevertheless, the toxicity levels of certain elements, such as F^-, SiO_2, etc., in groundwater sources fluctuate seasonally. The presence of pathogenic bacteria in the well water of CKDu-endemic and low-prevalence regions is comparatively higher than CKDu-free regions. However, the presence of bacteria (ex: *Aquitalea* sp., *Vogesella* sp.) that induce denitrification was higher in the CKDu nonendemic region. Lastly, the nutrients and SO_4^{2-} contents of the reservoirs in the Wilgamuwa region varied with the intensity of rainfall.

Conclusion

This study provides compelling multi-dimensional evidence that the hydrogeochemical environment, specifically elevated total hardness, fluoride, and dissolved silicon in groundwater, is strongly linked to the progression and geographic prevalence of CKDu in the Wilgamuwa region of Sri Lanka. Geogenic processes amplified by extreme evaporation under dry-zone climatic conditions are the primary drivers of elevated mineral content, while heavy metals are not implicated as causative agents.

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MULTIPROXY CHEMOSTRATIGRAPHIC AND BIOSTRATIGRAPHIC RECONSTRUCTION OF PALEOCENE-EOCENE MANNAR BASIN, SRI LANKA



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The Paleocene–Eocene interval represents one of the most significant climatic transition periods in Earth history, characterized by rapid global warming, oceanographic perturbations, and widespread ecological turnover associated with the Paleocene–Eocene Thermal Maximum (PETM). Despite its global significance, the equatorial Indian Ocean remains comparatively underrepresented in integrated paleoenvironmental studies. The Mannar Basin, located offshore northwestern Sri Lanka, forms part of a failed rift system developed during the breakup of the Indo–Lanka landmasses and preserves a thick Paleogene sedimentary succession with significant paleoenvironmental and hydrocarbon potential. Previous investigations have mainly focused on petroleum system evaluation and regional stratigraphy, whereas integrated geochemical and micropaleontological studies remain limited. This study presents an integrated geochemical and calcareous nannofossil investigation of the Paleocene–Eocene succession in the Mannar Basin using samples from the Dorado North exploration well. Whole-rock geochemistry and calcareous nannofossil biostratigraphy were integrated to reconstruct paleoenvironmental and tectonic evolution during the Middle Paleocene to Early Eocene interval. Geochemical proxies were used to evaluate paleoredox conditions, continental weathering intensity, and marine environmental changes, while calcareous nannofossil assemblages established a high-resolution biostratigraphic framework and documented ecological responses to climatic perturbations across the PETM.

Methodology

This study employed an integrated geochemical and micropaleontological approach to reconstruct the paleoenvironmental evolution of the Mannar Basin during the Middle Paleocene to Early Eocene interval using drill-cutting samples obtained from the Dorado North exploration well offshore Sri Lanka. The investigated succession spans depths between 2200 and 2700 m and includes the Paleocene–Eocene Thermal Maximum (PETM) interval. Whole-rock geochemical analyses involving major, trace, and rare earth elements (REE+Y) were conducted using X-ray fluorescence (XRF) and Inductively Coupled Plasma Mass Spectrometry (ICP-MS). Geochemical proxies including U/Th, V/Cr, Sr/Cu, Sr/Ba, Rb/Sr, and REE

anomalies were used to evaluate sediment provenance, tectonic setting, paleosalinity, continental weathering intensity, and paleoredox conditions. Calcareous nannofossil smear slides were prepared using standard procedures and examined using polarizing microscopy and scanning electron microscopy (SEM). Identified taxa were grouped according to ecological affinities to reconstruct sea-surface temperature fluctuations, nutrient dynamics, and ecological stress associated with climatic perturbations during the PETM.

Results and Discussion

The studied Paleocene–Eocene succession comprises mixed carbonate–siliciclastic sediments, including calcareous sandstone, mudstone, marlstone, and argillaceous marl. Stratigraphically, the succession was subdivided into the Middle Paleocene (MP), Late Paleocene (LP), and Paleocene–Eocene boundary (P/E) intervals based on lithological, geochemical, and micropaleontological variations. Major element geochemistry revealed elevated CaO contents within the P/E interval (19.95–21.30 wt.%) together with depletion of siliciclastic-associated oxides such as SiO_2 and MgO, indicating reduced terrigenous influx and increased carbonate accumulation during the PETM. PAAS-normalized trace- and rare-earth-element (REE) patterns showed light-REE enrichment, with a mean (La/Yb) ratio of 1.22, together with negative Ce anomalies.

In combination with elemental proxy ratios, these patterns indicate variations in terrigenous input, continental weathering, and marine redox conditions. Elemental proxy ratios including U/Th, V/Cr, and Sr/Cu further indicated significant paleoenvironmental fluctuations. Mean U/Th ratios increased from 0.10–0.11 in the the MP and LP intervals to 0.15 within the P/E interval, while Sr/Cu ratios reached 67.04 during the PETM. These geochemical signatures collectively indicate intensified greenhouse conditions, enhanced continental weathering, fluctuating paleosalinity, and dysoxic to mildly suboxic depositional conditions associated with the PETM. Calcareous nannofossil assemblages displayed moderate to good preservation throughout the studied interval, with 67 identified species distributed between biozones NP5 and NP10. Significant paleoecological turnover was observed across the PETM interval. The Late Paleocene assemblages were dominated by *Fasciculithus*, *Toweius*, and *Coccolithus*, whereas the P/E interval recorded a marked decline in *Fasciculithus* diversity and abundance together with the proliferation of *Coccolithus pelagicus* and increased *Discoaster* diversity. The persistence of Fasciculithus into the lower NP10 Zone suggests a diachronous extinction pattern within the equatorial Indian Ocean compared to Atlantic and Tethyan records, likely reflecting regional paleoceanographic buffering. Simultaneously, increased *Discoaster* abundance indicates warm, oligotrophic, and stratified surface-water conditions during the PETM, while the later dominance of small *Reticulofenestra* and *Coccolithus* suggests progressive eutrophication and enhanced nutrient influx during the Early Eocene.

The integration of geochemical and micropaleontological datasets demonstrates that the Mannar Basin recorded a complex interplay between global climatic perturbations and regional tectonic forcing during the Paleocene–Eocene transition. The integrated multiproxy evidence indicates that the Mannar Basin recorded PETM-related climatic and oceanographic perturbations superimposed on the regional evolution of a passive-margin sedimentary basin. The combined multiproxy evidence establishes the Mannar Basin as an important equatorial Indian Ocean archive for reconstructing Paleogene paleoceanographic and paleoenvironmental evolution (Figure 1).

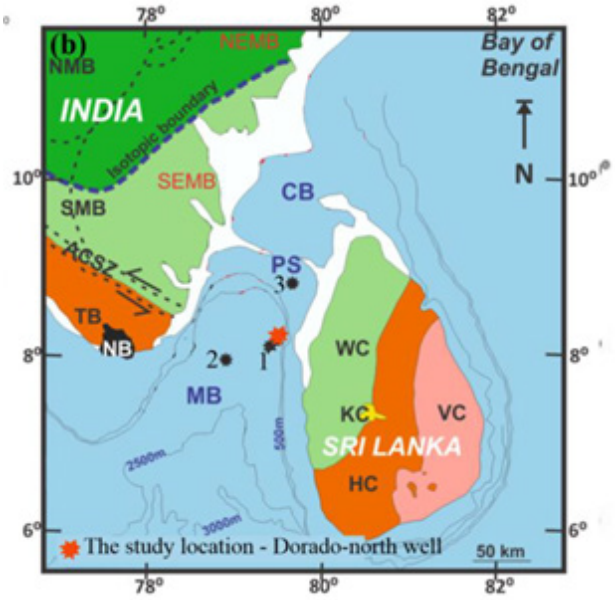


Figure 1: Location of Mannar Basin and some exploration wells drilled in Sri Lankan counterpart. ((1) Dorado, (2) Barracuda, (3) Pearl-1 hydrocarbon exploration wells). (CB = Cauvery Basin; HC = Highland complex; KC = Kadugannawa complex; MB = Mannar Basin; PS = Palk Strait; VC = Vijayan complex; WC = Wanni complex) Modified after Ratheesh-Kumar et al. (2020)

Conclusion

This study presents an integrated geochemical and calcareous nannofossil reconstruction of the Paleocene–Eocene succession in the Mannar Basin, Sri Lanka. Multiproxy evidence reveals significant PETM-related environmental perturbations, including intensified continental weathering, fluctuating redox conditions, ecological turnover, and tectonically influenced sediment influx. The findings establish the Mannar Basin as an important equatorial Indian Ocean archive for understanding coupled climatic, oceanographic, and tectonic controls on Paleogene paleoenvironmental evolution.

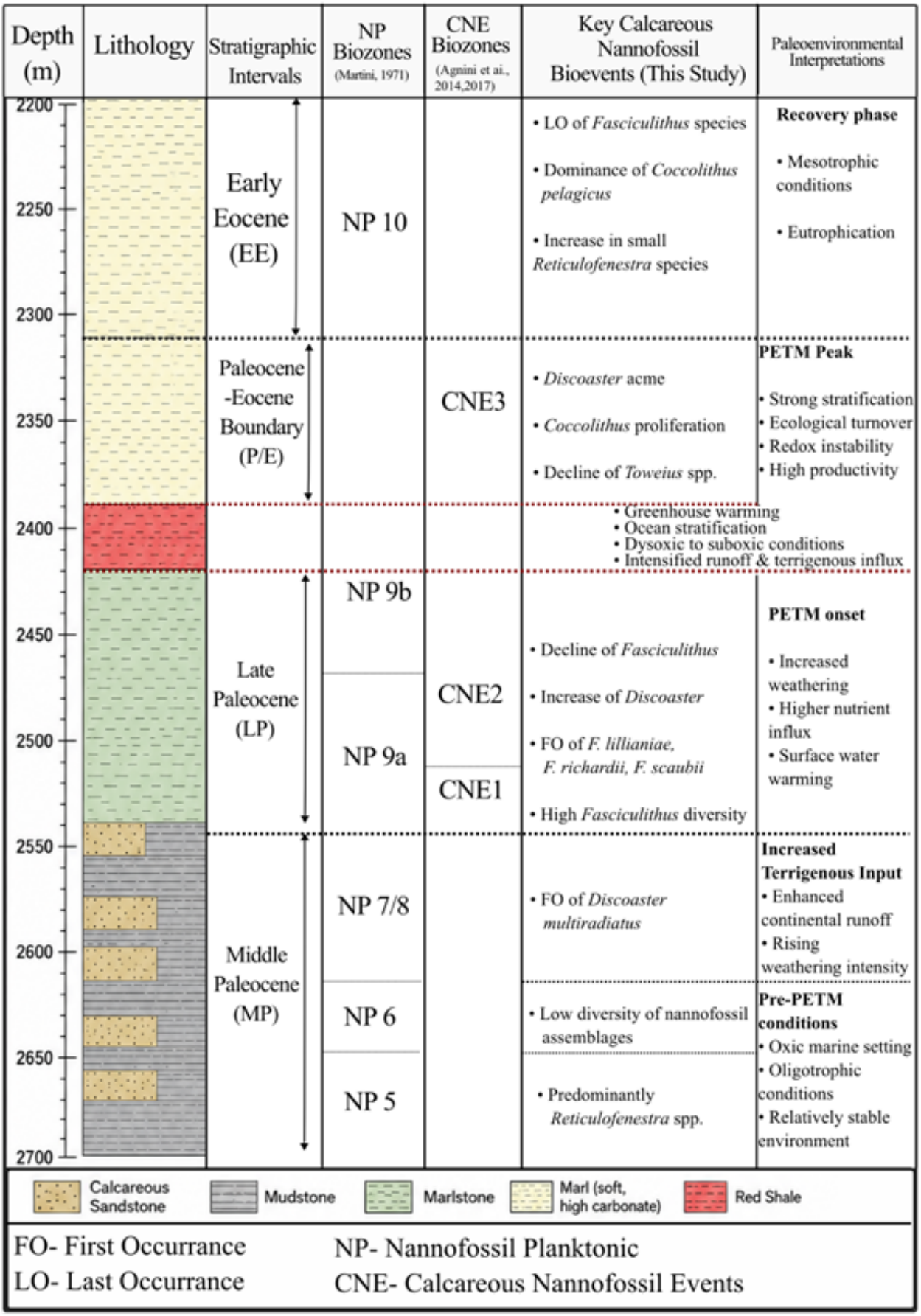


Figure 2: Integrated stratigraphic framework of the Paleocene–Eocene succession in the Dorado North well, Mannar Basin, Sri Lanka, showing lithology, calcareous nannofossil biozones, key bioevents, and paleoenvironmental changes across the PETM.

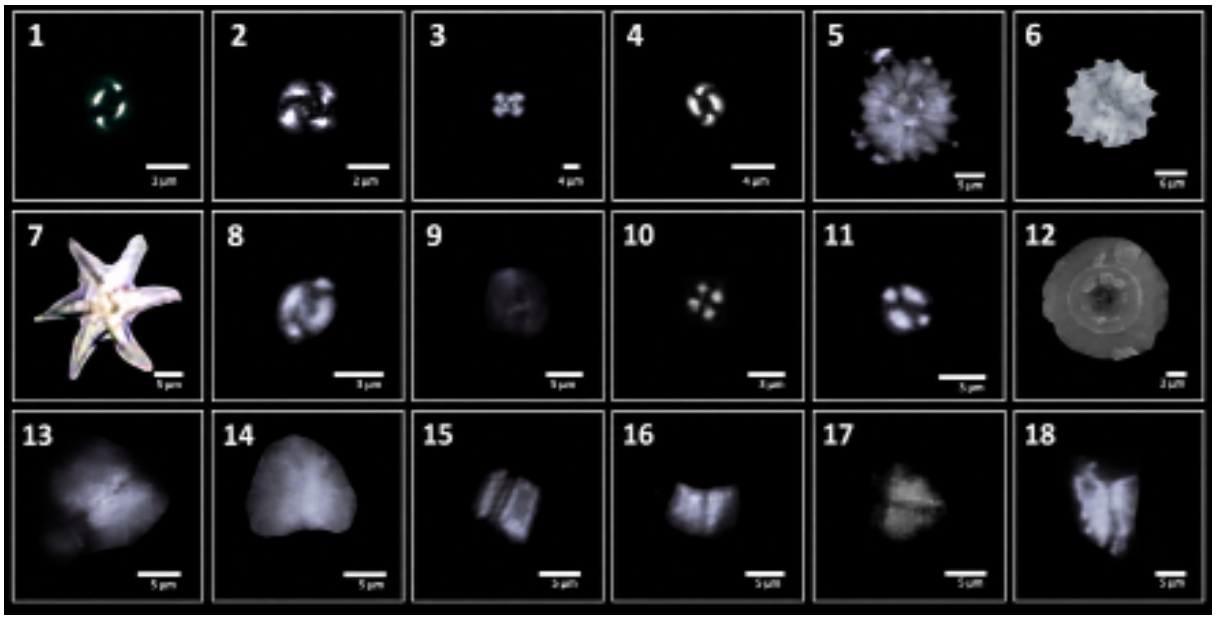


Figure 3: Representative calcareous nannofossils from the studied succession: 1 *Reticulofenestra martini*, 2 *Reticulofenestra gartner*i, 3 *Reticulofenestra bisecta*, 4 *Reticulofenestra minuta*, 5 *Discoaster salisburgensis*, 6 *Discoaster multiradiatus*, 7 *Discoaster lodoensis*, 8 *Toweius selandianus*, 9 *Toweius occultatus*, 10 *Toweius rotundus*, 11 *Coccolithus pelagicus*, 12 *Ericsonia subpertusa*, 13 *Fasciculithus tympaniformis*, 14 *Fasciculithus alanii*, 15 *Fasciculithus involutus*, 16 *Fasciculithus lillianiae*, 17 *Fasciculithus richardii*, 18 *Fasciculithus schaubii*

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SOIL CARBON DYNAMICS AND SOIL PHYSICO-CHEMICAL PROPERTIES IN TROPICAL MONTANE FORESTS (TMFs) IN SRI LANKA



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Tropical montane forests (TMFs) are unique high-elevation ecosystems occurring between approximately 800 and 3,500 m in tropical regions, including Africa, Asia, and America. These forests are characterized by persistent cloud cover, cool and moist climatic conditions, and high levels of biodiversity and endemism. In Sri Lanka, TMFs are classified into upper (1,500–2,500 m) and lower montane forests (1,000–1,500 m), with key locations including Horton Plains, Knuckles, Pidurutalagala, Hakgala, Sinharaja-Enasalwatta, and Rilagala. TMFs play key roles in carbon sequestration, climate regulation, and water conservation. However, they are increasingly threatened by deforestation and climate change, making their conservation and restoration essential for maintaining ecosystem stability.

Soil is the largest terrestrial carbon (C) reservoir, storing about two-thirds of global terrestrial carbon. Soil carbon exists in both organic and inorganic forms, with soil organic carbon (SOC) comprising a wide range of materials from easily decomposable residues to stable, recalcitrant compounds and microbial biomass. SOC plays a critical role in regulating soil hydrological, biological, and chemical functions. Its stabilization occurs through three primary mechanisms: biochemical recalcitrance, formation of organo-mineral complexes, and physical protection within soil aggregates, with organo-mineral interactions being the most effective. Soil C dynamics involve the movement and transformation of carbon between soil, plants, and the atmosphere, and are influenced by factors such as climate, soil type, vegetation, and human activities. These dynamics are governed by complex processes including erosion, microbial decomposition, transport of dissolved and particulate carbon, and aggregation. Since photosynthesis is the primary source of SOC, understanding its stabilization and turnover is essential for climate regulation. Advanced techniques such as stable and radiocarbon isotopes are used to study soil carbon processes. Although soil C dynamics have been extensively studied in tropical rainforests globally, there is a notable lack of research focusing on tropical montane forests in Sri Lanka, highlighting the need for further investigation.

Soil physicochemical properties are largely influenced by clay mineral composition and play a critical role in determining soil fertility, C storage, and ecosystem functioning. Most SOC is concentrated in the topsoil, where nutrient availability (N, P, K), organic matter, and water content regulate plant growth. In tropical forest ecosystems, there is a strong interdependence between soil properties and vegetation, with below-ground characteristics significantly influencing above-ground productivity. Soil texture, mineralogy, and

chemistry govern the capacity of soils to retain carbon, nutrients, and water. Despite extensive global research on tropical soils, there is limited understanding of soil physicochemical properties and their relationship with soil carbon dynamics in TMFs of Sri Lanka. Climate change, including rising CO_2 levels and warming, may not enhance productivity in TMFs due to nutrient limitations, and the future role of these soils as carbon sinks remains uncertain. Additionally, significant deforestation and fragmentation have reduced TMF extent, threatening their ecological functions. Although above-ground data are relatively well documented, below-ground soil information is scarce.

The objectives of this study are to evaluate the variation in soil physical and chemical properties in TMFs in Sri Lanka and to investigate the mechanisms of soil C stabilization. Specifically, this study aims to quantify the distribution of SOC among different pools. In addition, the study seeks to determine the mineralization rate of SOM and estimate the annual C–CO_2 emissions from TMF soils in Sri Lanka.

Methodology

This study was conducted in four permanent sampling plots (PSPs) located along an altitudinal gradient (1,042–2,132 m) in TMFs of Sri Lanka, including Sinharaja-Enasalwatta (ENS 1 and ENS 2), Pidurutalagala (PTG), and Horton Plains (HNP). A total of 17 near-surface soil samples (0–25 cm depth) were collected from each PSP following RAINFOR standard protocols.

Volumetric water content (VWC) and unsaturated hydraulic conductivity were measured in situ using a TDR moisture meter and a Minidisk Infiltrometer, respectively. Soil properties were determined through standard methods: bulk density by oven-drying core samples, soil texture by the hydrometer method, aggregate stability by the Le Bissonnais method, cation exchange capacity (CEC) by ammonium acetate method, and SOC using the Walkley–Black method. Major and trace elements, and rare earth elements (REEs) were measured using microwave digestion followed by ICP-MS and atomic absorption spectrophotometry. Total C and N were determined using a CHN analyzer, while available nutrients (N, P, K) were analyzed in a certified laboratory.

Soil C dynamics were assessed by a fractionation method based on Six et al. (2000, 2002), which separated SOC into unprotected, physically protected, chemically protected, and biochemically protected pools through sequential wet sieving, density separation using sodium polytungstate, dispersion, and acid hydrolysis. A 60-day laboratory incubation experiment was conducted to measure SOM mineralization, in which CO_2 evolution was captured using sodium hydroxide and quantified through titration with hydrochloric acid. Stable carbon isotope ($\delta^{13}C$) analysis was performed using isotope ratio mass spectrometry (IRMS). Statistical analyses, including analysis of variance (ANOVA), mean separation, and correlation analysis, were conducted using SAS software, with significance determined at the 95% confidence level.

Results and Discussion

Significant differences ($P < 0.05$) among PSPs were found in bulk density, porosity, sand and silt contents, soil aggregate stability, pH, Eh, CEC, EC, SOM, exchangeable K, Mg, Mn, Cu, Zn, Al, Cd, Pb, ΣREE, rate of CO_2 evolution, coarse particulate organic matter (POM) and intra-particulate organic matter (iPOM) fraction among different forests sites. Bulk density decreased with elevation, ranging from 1.38 to 0.88 Mg m^{-3}, mainly due to higher SOM and improved soil structure at higher elevations. Soil texture was dominated by loamy sand and sandy loam, with sand content exceeding 70% in all plots. Aggregate stability ranged from 1.25-1.43 in fast wetting (FW), 1.18-1.70 in slow wetting (SW) and 1.16-1.58 in mechanical breakdown (MB). The size of the aggregate fraction was >2 mm for FW and SW treatments of all plots, while MB was > 0.25 mm. Aggregate stability indicated generally stable soils, although macroaggregate formation tended to decline at higher elevations.

Soils were strongly acidic, with pH values between 4.8 and 5.3, and Eh values above 300 mV indicated well-drained aerobic conditions. EC and CEC increased with elevation, largely due to higher SOM and base cation contents. SOM and SOC were high across all sites and increased with elevation, with SOC ranging from 3.54% in ENS 1 to 6.19% in PTG. Total N also increased with elevation, while available N remained constant at 0.03%. Trace elements were generally higher in upper plots, especially PTG and HNP, reflecting the influence of SOM, pH, leaching, and parent material. The average total REE contents of ENS 1, ENS 2, PTG, and HNP soils were 169, 110, 127, and 62 mg kg^{-1}, respectively. REE distribution appeared to be controlled mainly by parent material, with additional influence from climate, soil properties, and vegetation. All measured physico-chemical properties, micronutrients, and element concentrations were expected to be favorable for the productivity and sustainability of these forests.

Stabilised SOC fractions were observed as ENS 2 > ENS1 > PTG > HNP soils, with values of 69, 62, 60 and 59%, respectively. The unprotected SOC pool accounted for 22.21–39.41% of total SOC, physically protected SOC accounted for 16–25%, chemically protected SOC contributed 10.14–20.56%, and biochemically protected SOC contributed 9.52–22.52%. The stable chemically and biochemically protected pools showed no clear elevation trend, suggesting stronger control by mineralogy, soil texture, and site-specific conditions. The maximum and minimum CO_2 emission rates were 67.6 and 28.8 mg C kg^{-1} soil day^{-1} in PTG and ENS,

respectively. PTG showed the highest cumulative CO_2 emission (4,071 mg C kg^{-1} soil) and had the highest total protected and unprotected SOC fractions. Stable carbon isotope values around −27‰ indicated that SOM mainly originated from C_3 vegetation, with no significant elevation effect. Overall, Sri Lankan TMF soils store substantial carbon, especially at higher elevations, but these carbon pools may be vulnerable to increased mineralization and CO_2 release under future warming.

Conclusion

This study demonstrates that Sri Lankan TMFs function as highly dynamic and sensitive soil systems, where altitude-mediated environmental gradients play a central role in regulating soil properties and ecosystem services. Most of the measured parameters were within ranges appropriate for supporting the growth and ecosystem functions of TMFs. The soil C sequestration observed in the studied TMFs can be attributed to temperature fluctuations, vegetation characteristics, environmental conditions, and pedo-geological processes. The findings provide an important baseline for understanding soil processes in TMFs and highlight the need for integrated, multidisciplinary research to assess future responses of these ecosystems to climate change and anthropogenic pressures.

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SPATIAL AND TEMPORAL ANALYSIS OF NO_2 AND SO_2 POLLUTION IN SRI LANKA: A GIS AND REMOTE SENSING APPROACH



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Air pollution has emerged as one of the most pressing environmental challenges of the twenty-first century, with nitrogen dioxide (NO_2) and sulphur dioxide (SO_2) among the most harmful atmospheric pollutants affecting both human health and ecosystems worldwide. In Sri Lanka, the rapid pace of urbanisation, industrial growth, and the continued reliance on fossil fuels for energy have driven a steady rise in ambient concentrations of these pollutants, particularly in western coastal cities and industrial corridors. Yet, the country's air quality monitoring infrastructure remains limited in spatial coverage, predominantly concentrated in urban centres, leaving large rural and suburban areas without systematic data.

Conventional ground-based monitoring cannot fully characterise the complex spatial and temporal dynamics of NO_2 and SO_2 across an island as geographically diverse as Sri Lanka. Satellite remote sensing, particularly the Sentinel-5P/TROPOMI instrument operated by the European Space Agency, offers a transformative solution: near-daily, country-wide observations at resolutions sufficient to resolve district-level pollution gradients. When coupled with Geographic Information Systems (GIS) and statistical forecasting, such data enable a comprehensive understanding of how pollutant concentrations vary by season, year, and land-use type , and how they are projected to evolve.

This study addresses the critical need for detailed, long-term pollution data in Sri Lanka. By integrating Sentinel-5P satellite observations with GIS spatial analysis and Seasonal Autoregressive Integrated Moving Average (SARIMA) time-series modelling, the research maps NO_2 and SO_2 concentrations across all 25 districts of Sri Lanka from 2019 to 2024, identifies pollution hotspots, evaluates seasonal and interannual trends, and generates district-level forecasts through 2027. The findings aim to provide an evidence base for targeted air quality management, urban planning, and environmental policy in Sri Lanka.

Methodology

Monthly NO_2 and SO_2 concentrations were extracted from Sentinel-5P TROPOMI Level-3 products in both Near Real-Time (NRTI) and Offline (OFFL) processing streams via the GEE JavaScript API, covering Sri Lanka's bounding box (79.65°–81.90°E, 5.90°–9.85°N) for 2019–2024. Negative retrieval values were masked, and column number densities (mol/m²) were converted to ppb using altitude-adjusted air column density calculations. Monthly composites were exported as GeoTIFF files for spatial analysis in ArcGIS and as CSV files for time-series modelling. Pollution grids were overlaid with administrative boundaries, population

data, road networks, and locations of healthcare facilities and residential areas, and hotspot analysis identified statistically significant clusters of elevated concentrations. Satellite-derived concentration series were validated against CEA ground measurements at Battaramulla (Colombo, ~30 m) and Kandy (~500 m) to assess temporal trend alignment and characterise sources of discrepancy, including spatial resolution mismatches, cloud and aerosol interference, and overpass timing differences.

District-level time series were pre-processed using z-score outlier detection (±3σ threshold), with flagged values replaced by month-wise medians to preserve seasonal structure while eliminating sensor artefacts. A uniform SARIMA$(1,1,1)(1,1,1)_{12}$ specification was then fitted independently to each district's monthly NO_2 and SO_2 series in Python using the statsmodels library (Google Colab environment). The non-seasonal components captured short-lag autoregression, first differencing for stationarity, and moving-average noise, while the seasonal components modelled the annual periodicity with period s = 12. An evaluation phase trained models on 2019–2022 data and assessed 2023–2024 forecasts against observed values using MAE, MSE, RMSE, and MAPE. Validated models were retrained on the full 2019–2024 record and extended to generate 36-month district-level forecasts for 2025–2027.

Results and Discussion

The NRTI and OFFL satellite maps consistently identified the western coastal belt; Colombo, Gampaha, and Kalutara, as the dominant NO_2 pollution zone across the entire study period. Colombo recorded the highest concentrations throughout, attributable to its dense traffic networks, major port operations, and industrial activity, while northern and highland districts such as Mullaitivu, Nuwara Eliya, and Badulla showed near-background levels owing to minimal emission sources and effective natural dispersion. SO_2 exhibited a distinctly different spatial signature, with the highest concentrations confined to industrial point sources: petroleum refining and combustion activities in Colombo, manufacturing industries in Gampaha, and coal-fired thermal power generation in Puttalam. This spatial divergence between the two pollutants confirms that traffic-oriented controls alone are insufficient and that sector-specific emission regulations targeting industrial and energy facilities are equally necessary.

Both pollutants displayed strong seasonal variability governed by Sri Lanka's monsoon cycle. Concentrations peaked during the dry season (November–April) when stable atmospheric conditions suppressed vertical mixing and allowed emissions to accumulate near the surface, and declined markedly during the Southwest Monsoon (May–September) through wet deposition and wind-driven dispersion. Major interannual signals were also captured: a sharp NO_2 decline during COVID-19 mobility restrictions (April–June 2020) and Sri Lanka's 2022 fuel crisis (June–September) confirmed the direct dependence of urban NO_2 on vehicular traffic, while SO_2 remained comparatively stable through both disruptions, reflecting continued industrial and power-generation baseload. Overlaying December 2024 pollution grids with residential settlement and healthcare facility data further revealed that western and central urban populations face persistent rather than episodic NO_2 and SO_2 exposure, with many major hospitals in Colombo, Gampaha, and Kandy co-located within moderate-to-high pollution zones, raising particular concern for patients, the elderly, and children with pre-existing respiratory or cardiovascular conditions.

The SARIMA$(1,1,1)(1,1,1)_{12}$ model demonstrated robust performance for NO_2, with evaluation-phase MAPE ranging from 5.9% (Matale, NRTI) to 20.1% (Colombo, OFFL) and averaging below 12% across all 25 districts, a level regarded as good to excellent for environmental time-series forecasting. SO_2 MAPE values were higher overall, particularly in non-industrial districts where near-zero baseline concentrations amplified percentage errors; in high-emission districts such as Colombo (≈42–45%) and Puttalam (≈30–38%), performance was more moderate and practically interpretable. The 2025–2027 district-level forecasts identified three typologies: persistently elevated districts (Colombo, Gampaha, and Puttalam) forecast to maintain or increase concentrations, requiring immediate regulatory intervention; moderate districts with seasonal spikes (Kandy, Kurunegala, Jaffna, and Galle) showing intermittent dry-season peaks without a sustained upward trend; and stable or low-emission districts (Ampara, Mullaitivu, Badulla, and Nuwara Eliya) projected to retain near-background levels through 2027.

Conclusion

This study has demonstrated that Sentinel-5P TROPOMI satellite data, processed through Google Earth Engine and analysed with GIS spatial tools and SARIMA time-series models, provide a scientifically robust and cost-effective framework for comprehensive, district-level monitoring and forecasting of NO_2 and SO_2 air pollution across Sri Lanka. The six-year dataset (2019–2024) covering all 25 districts offers a level of spatial coverage and temporal resolution that is unattainable through the existing ground-based monitoring network alone.

Several key conclusions emerge. NO_2 pollution is primarily traffic-driven and concentrated in Sri Lanka's western urban corridor, exhibiting strong seasonal modulation by the monsoon cycle and clear sensitivity to major socio-economic disruptions such as the COVID-19 lockdowns and the 2022 fuel crisis. SO_2 pollution is industrial in character, with persistent hotspots near thermal power plants, petroleum facilities, and cement industries, showing far less sensitivity to traffic-related interventions. The spatial co-location of

elevated pollutant concentrations with residential and healthcare infrastructure in western and central Sri Lanka underscores urgent policy imperatives around emission standards, urban planning, and public health preparedness.

The SARIMA forecasting framework proved well-suited to capturing the seasonal and trend components of satellite-derived air quality data, delivering reliable NO_2 forecasts (mean MAPE below 12%) and interpretable SO_2 projections for all 25 districts through 2027. These district-level forecasts can directly support the Central Environmental Authority's planning processes, enabling proactive allocation of monitoring resources, timely public health advisories, and evidence-based setting of emission reduction targets.

Future research should pursue hybrid AI-SARIMA model incorporating Long Short-Term Memory (LSTM) networks or Gradient Boosting Machines to better capture non-linear pollution dynamics and sudden emission events. Integration of real-time meteorological data (wind speed, humidity, temperature) into the modelling chain would reduce uncertainty in atmospheric correction and dispersion estimates. A South Asian transboundary pollution assessment leveraging multi-satellite data fusion (Sentinel-5P, MODIS, VIIRS) would also quantify the contribution of regional emission sources to Sri Lanka's ambient air quality. Collectively, these extensions would move toward a real-time, AI-enhanced air quality decision-support system for Sri Lanka's environmental management authorities.

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HEAVY METAL BIOACCUMULATION POTENTIAL OF *Avicennia marina* IN TWO SELECTED MANGROVE HABITATS IN EASTERN SRI LANKA



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Heavy metal pollution has become one of the major environmental problems affecting coastal ecosystems around the world during the last few decades. In Sri Lanka, many coastal areas have been increasingly polluted by toxic heavy metals released from human activities such as agriculture, industrial waste, urban runoff, and improper waste disposal. These pollutants are eventually deposited in lagoons and coastal sediments, where they can remain for long periods and negatively affect aquatic organisms, ecosystem stability, and even human health through the food chain.

Mangrove forests are among the most important coastal ecosystems found in tropical and subtropical regions. They provide a wide range of ecological benefits, including shoreline protection, prevention of coastal erosion, support for biodiversity, nutrient cycling, and carbon storage. Mangroves also act as natural barriers against storms, cyclones, and tsunamis. In addition, these ecosystems help reduce global warming by absorbing and storing large amounts of carbon dioxide from the atmosphere.

Heavy metals such as chromium, zinc, coppe, lead, nickel, cadmium, cobalt, and arsenic are among the most commonly reported contaminants in coastal environments. Although some of these metals are essential micronutrients in small quantities, excessive concentrations become highly toxic to living organisms.

Heavy metal contamination affects water quality, sediment quality, aquatic biodiversity, and the overall ecological balance of coastal ecosystems. Coastal lagoons and estuaries are especially sensitive because they function as natural sinks where contaminants settle and accumulate over time. Therefore, understanding the distribution and accumulation of heavy metals in these environments has become an important area of environmental research.

Another major ecological importance of mangroves is their ability to reduce the impacts of climate change. Mangrove forests are highly efficient carbon sinks that absorb and store significant amounts of carbon dioxide from the atmosphere. Mangrove soils can retain carbon for long periods, making these ecosystems extremely important in controlling greenhouse gas emissions and reducing global warming. Studies have shown that mangrove ecosystems contribute significantly to blue carbon storage and help regulate the environmental balance of coastal regions.

In recent years, mangrove ecosystems have gained special attention because of their ability to trap and retain pollutants, especially heavy metals. Mangrove sediments contain fine-grained particles, clay minerals, organic matter, iron oxides, and sulfide compounds that can effectively adsorb and immobilize toxic metals. The dense root systems of mangrove plants help trap suspended particles and reduce the movement of contaminants into surrounding marine environments. As a result, mangrove ecosystems function as natural filters and pollution sinks in coastal regions.

Several studies conducted in different parts of the world have confirmed that mangrove plants possess the ability to absorb and accumulate heavy metals within their tissues. This process is known as phytoremediation or phytoextraction, where plants naturally remove or stabilize contaminants from the environment. Mangroves are particularly suitable for phytoremediation because they can survive under stressful environmental conditions such as high salinity, waterlogging, low oxygen levels, and fluctuating tides. Their ability to tolerate and accumulate pollutants makes them environmentally friendly and cost-effective solutions for pollution control.

Among different mangrove species, *Avicennia marina* is considered one of the most effective species for heavy metal accumulation and tolerance. This species is widely distributed in coastal regions and is commonly found in lagoon ecosystems of Sri Lanka. The species has specialized root systems and physiological adaptations that allow it to absorb, store, and sometimes excrete excess salts and toxic metals. Previous studies have shown that *A. marina* can effectively accumulate metals such as zinc and copper while restricting the movement of highly toxic metals like lead into upper plant tissues. Most heavy metals are retained within the roots, which act as protective barriers against the spread of contaminants within the plant.

Despite the ecological importance of mangroves and their potential role in pollution control, limited studies have been conducted regarding heavy metal accumulation in mangrove ecosystems of eastern Sri Lanka. Batticaloa Lagoon and Uppar Lagoon are two important coastal lagoon systems in the eastern region that contain natural mangrove vegetation dominated by *A. marina.*

This study was conducted to evaluate the phytoremediation potential of *A. marina* in Batticaloa and Uppar lagoons by analyzing heavy metal concentrations in sediments and different plant parts including roots, stems, and leaves.

Methodology

The study was conducted in two lagoon ecosystems located on the eastern coast of Sri Lanka, namely Batticaloa Lagoon and Uppar Lagoon. These lagoons were selected because they contain naturally growing mangrove vegetation dominated by *A. marina*. Batticaloa Lagoon is one of the largest lagoons in the country, while Uppar Lagoon is relatively smaller and experiences less human disturbance.

Three sampling sites were selected from Batticaloa Lagoon and another three from Uppar Lagoon. Sediment samples were collected along transects extending from the mangrove root area towards the center of the lagoon. Four sediment samples were collected from each transect to observe changes in heavy metal concentration with distance from the mangrove roots.

The plant samples including roots, stems, and leaves of mature *A. marina* plants were also collected from both lagoons. During sample collection, environmental parameters including pH were measured. All collected samples were carefully stored in clean plastic bags and transported to the laboratory for analysis. Sediment and plant samples were cleaned and oven dried before analysis. Grain size analysis was carried out using sieve analysis to determine the sediment texture. Heavy metal concentrations including zinc, copper, lead, chromium, nickel, cadmium, cobalt, and arsenic were measured using Inductively Coupled Plasma Mass Spectrometry (ICP-MS).

Results and Discussion

The sediments of both Batticaloa and Uppar lagoons contained different concentrations of heavy metals. Among the analyzed elements, chromium, zinc, and copper showed relatively higher concentrations compared to the other metals. Batticaloa Lagoon generally showed higher contamination levels than Uppar Lagoon, likely due to greater human activities and higher sediment accumulation in the area.

Sediment characteristics such as grain size and organic matter content had a strong influence on heavy metal accumulation. Fine-grained sediments with higher clay and silt contents were found to retain more heavy metals because smaller particles have a larger surface area for adsorption.

The study also revealed that *A. marina* accumulated heavy metals mainly in its roots, followed by stems and leaves. The roots showed the highest concentrations because they act as the first barrier against toxic substances entering the plant. Essential metals such as zinc and copper were accumulated more effectively than non-essential metals such as lead and chromium.

The study identified a possible environmental concern, i.e., heavy metals stored within plant tissues may re-enter the ecosystem when leaves and other plant materials decompose. This could increase the risk of contamination within aquatic food chains. Therefore, proper management methods such as harvesting contaminated plant material and safe disposal practices are important for long-term environmental protection.

Conclusion

This study highlighted the importance of mangrove ecosystems in controlling heavy metal pollution in coastal environments. The sediments of Batticaloa and Uppar lagoons were found to contain varying levels of toxic heavy metals, especially chromium, zinc, and copper. The mangrove species *A. marina* showed a strong

ability to absorb and store these metals, particularly within its root system.

The findings suggest that *A. marina* can be considered an effective and environmentally friendly option for phytoremediation of polluted coastal ecosystems. At the same time, mangroves provide several additional ecological benefits such as coastal protection, biodiversity conservation, and carbon sequestration.

However, long-term monitoring and proper management are necessary as accumulated heavy metals may be released back into the environment through plant decomposition.

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IMPACTS OF TROPICAL CYCLONES DEVELOPED IN THE BAY OF BENGAL ON SRI LANKAN RAINFALL AND EXTREME RAINFALL EVENTS



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Tropical cyclones (TCs) are among the most destructive natural hazards affecting tropical and subtropical regions worldwide. They are intense low-pressure systems formed over warm ocean waters with sustained high wind speeds, accompanied by heavy rainfall, strong winds, and organized convection. The formation and intensification of TCs depend on favorable atmospheric and oceanic conditions, including sea surface temperatures above 26.5°C, sufficient moisture, atmospheric instability, and the Coriolis force. Due to their destructive nature, TCs cause severe environmental, social, and economic impacts across many regions of the world.

The North Indian Ocean, particularly the Bay of Bengal (BOB) and the Arabian Sea, is one of the major cyclone genesis regions globally. Among these regions, the BOB is recognized as highly vulnerable to cyclonic activity because of its unique geographical and climatic characteristics. The semi-enclosed structure and funnel shaped coastline of the BOB enhance cyclone formation and intensification, frequently directing storms toward densely populated areas. Consequently, TCs originating in the BOB often produce heavy rainfall, strong winds, flooding, and storm surges across South Asian countries.

Sri Lanka, located in close proximity to the BOB and the Arabian Sea, is frequently affected by the indirect impacts of TCs, particularly during the Southwest and Northeast monsoon seasons. Although direct cyclone landfalls over Sri Lanka are relatively rare, the island commonly experiences the influence of outer rainbands and peripheral circulation associated with nearby cyclonic systems. These conditions can generate intense rainfall events, floods, landslides, and strong winds, causing significant impacts on communities, agriculture, infrastructure, and the national economy. In some cases, cyclone-induced rainfall contributes positively to water resources and agricultural activities. However, extreme rainfall events often create serious disaster situations.

Previous studies have highlighted the vulnerability of the BOB region to TCs and associated hydrometeorological hazards. However, limited attention has been given to understanding the localized impacts of BOB cyclones on rainfall variability and extreme rainfall events in Sri Lanka. Existing research mainly focuses on broader regional impacts, while detailed analyses of rainfall distribution, cyclone tracks, cyclone intensity, and their interactions with Sri Lankan atmospheric conditions remain limited. Furthermore, the influence of climate change on cyclone-induced rainfall extremes in Sri Lanka has not been adequately investigated.

Understanding the relationship between TCs and rainfall patterns in Sri Lanka is essential for improving disaster preparedness, early warning systems, and climate resilience strategies. Therefore, this study investigates the impacts of TCs developed in the BOB on rainfall and extreme rainfall events in Sri Lanka. The study focuses on examining the relationship between cyclone genesis locations and rainfall distribution across the Sri Lanka, analyzing cyclone induced rainfall intensity and frequency, and identifying vulnerable regions requiring enhanced disaster preparedness measures. The findings of this research are expected to contribute to improved understanding of cyclone-rainfall interactions and support effective disaster risk reduction (DRR).

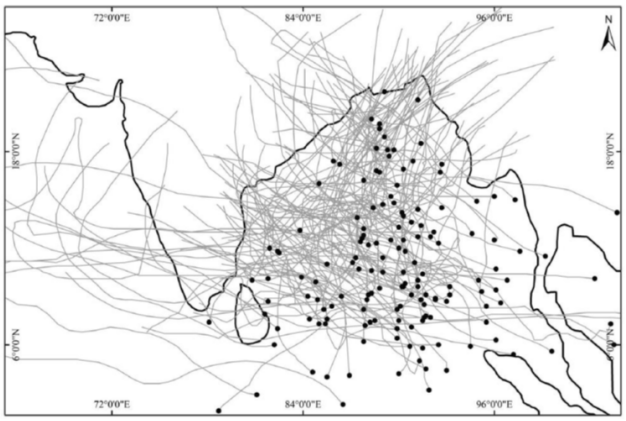


Figure 1: Spatial distribution of TC genesis points and tracks in the BOB from 1972 to 2017 (Source: Bhardwaj and Singh, 2020)

Methodology

This study investigated the impacts of TCs originating in the BOB on rainfall and extreme rainfall events in Sri Lanka using meteorological data analysis and GIS techniques.

Historical cyclone best-track data from 1982 to 2022 were obtained from the India Meteorological Department (IMD), including information on cyclone location, intensity, pressure, and wind speed. Daily rainfall data from 282 meteorological stations and monthly wind speed data from 23 stations across Sri Lanka were collected from the Department of Meteorology (DOM), Sri Lanka.

Cyclones were classified into six predefined BOB regions based on IMD classifications. North West Bay (NWB), North East Bay (NEB), West Central Bay (WCB), East Central Bay (ECB), South West Bay (SWB), and South East Bay (SEB). Python scripts were developed to process cyclone datasets and identify cyclone genesis locations according to their latitude and longitude coordinates.

Rainfall data were organized according to cyclone occurrence periods, and total rainfall associated with each cyclone event was calculated for all rainfall stations in Sri Lanka. Spatial rainfall distribution maps were generated using ArcGIS Pro software. The Kriging interpolation method was applied to produce rainfall distribution maps corresponding to cyclones originating from different BOB regions.

Statistical analyses were conducted to examine relationships between cyclone characteristics and rainfall patterns in Sri Lanka. Cyclone frequency, seasonal distribution, regional distribution, and district-level vulnerability were analyzed using charts and graphical methods. In addition, the percentage contribution of cyclone-induced rainfall to total rainfall was calculated and spatially mapped using GIS techniques.

Monthly wind speed data from 2014 to 2021 were further analyzed to assess the influence of cyclones on wind patterns across Sri Lanka. Time series graphs were developed for each meteorological station, and cyclone periods were overlaid to identify variations associated with TC activity.

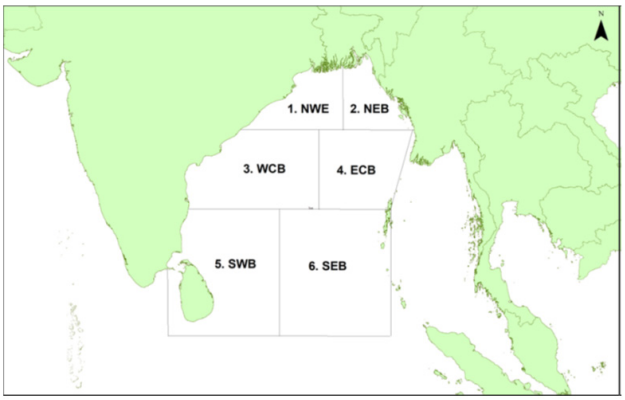


Figure 2: The subdivisions of the BOB based on IMD classification

Results and Discussion

The analysis revealed that TCs originating in different regions of the BOB produce distinct rainfall patterns across Sri Lanka. Cyclones formed in the South West Bay (SWB), South East Bay (SEB), and East Central Bay (ECB) regions generated the highest rainfall over the island, particularly in the wet zone districts such as Nuwara Eliya, Rathnapura, Kegalle, Colombo, and Kandy. In contrast, cyclones originating in the North East Bay (NEB) showed minimal influence on Sri Lankan rainfall.

Spatial analysis indicated that the central highlands and southwestern regions consistently received higher cyclone induced rainfall, while the Northern, Eastern, and parts of the North Central provinces experienced comparatively lower rainfall amounts. The findings suggest that cyclone genesis location strongly influences

rainfall distribution patterns across Sri Lanka.

The study further showed that cyclone-related rainfall contributes significantly to total annual rainfall in several districts, highlighting the importance of TCs in Sri Lanka's hydrological variability. Wind pattern analysis also indicated noticeable variations during cyclone periods, particularly in coastal and vulnerable regions.

Overall, the results emphasize the importance of improved early warning systems, flood management strategies, and district-level disaster preparedness measures, especially in highly vulnerable regions frequently affected by cyclone induced rainfall and strong winds.

Conclusion

This study examined the spatial and temporal patterns of cyclone-induced rainfall and wind impacts in Sri Lanka from 2014 to 2021, focusing on cyclones originating in the BOB. The results showed that cyclones formed in the North West Bay, South West Bay, South East Bay, and Eastern Central Bay of BOB regions significantly influence rainfall and wind patterns of Sri Lanka, particularly during the inter-monsoon and Northeast monsoon seasons, with October and November identified as peak cyclone months.

Twelve districts, including Kegalle, Kandy, Nuwara Eliya, Ratnapura, Galle, Matara, Kurunegala, Puttalam, Mannar, Kilinochchi, Vavuniya, and Jaffna, were identified as being highly vulnerable to intense rainfall during cyclonic periods. Central highland districts experienced enhanced rainfall due to orographic effects, increasing the risk of floods and landslides, while wet zone and northern districts showed heightened exposure to flood hazards during cyclone events.

Coastal districts such as Batticaloa, Hambantota, Trincomalee, Jaffna, and Puttalam experienced stronger wind impacts because of their proximity to cyclone paths. Districts such as Jaffna and Puttalam were exposed to both heavy rainfall and strong winds, making them critical areas for disaster preparedness. The long-term cyclone analysis (1982–2022) revealed a relatively stable cyclone frequency with strong seasonal occurrence between May and December, especially in October and November.

The study also highlighted the cascading nature of cyclone-related hazards, including floods, landslides, and lightning events, particularly in geographically vulnerable and highly urbanized areas. Overall, the findings emphasize the importance of localized and data-driven disaster management strategies to improve climate resilience, early warning systems, and preparedness planning in Sri Lanka.

Recommendations

The study recommends strengthening disaster resilience of Sri Lanka through localized and integrated disaster management strategies. District-level preparedness plans should address specific risks related to rainfall, flooding, landslides, wind, and lightning, particularly in high-risk districts such as Jaffna and Puttalam. Enhancing early warning systems using seasonal cyclone trends and real-time cyclone data is essential for improving preparedness and response. Infrastructure improvements, including better drainage systems, flood barriers, slope stabilization, and stormwater management, are especially important in urban, coastal, and highland regions.

The study also highlights the need for community awareness programs, and climate-resilient agricultural practices supported by insurance schemes in vulnerable areas. Future research should incorporate longer-term and high-resolution meteorological data to improve predictive capabilities. In addition, stronger coordination among government agencies, local authorities, NGOs, and communities is necessary for effective disaster risk reduction and resource management. Overall, these measures will help minimize cyclone-related impacts and strengthen long-term climate resilience in Sri Lanka.

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FINDING A NEAR-OPTIMAL SOLUTION TO INTEGRATED ROUTING AND SCHEDULING PROBLEM WITH CROSS-DOCKING STRATEGY IN SUPPLY CHAIN



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The logistics strategy known as cross-docking was introduced in the 1930s to reduce storage costs and enhance customer satisfaction by shortening delivery lead times and became widely adopted in the 1980s. A cross-docking center (CDC) not only collects shipments from the suppliers but also dispatches them to the customers. After the 1980s, cross-docking received more attention from the practitioners and the researchers. Subsequently, researchers started to work on different aspects of cross-docking. In this doctoral research, as per the recommendation made by the literature survey on the supply chain, problems of 'vehicle routing with cross-docking' and 'vehicle scheduling at the CDC' are integrated to improve the efficiency of the supply chain. In this study, the internal operations at a CDC are named 'Moving Shipments'. Figure 1 illustrates the operations that take place inside a CDC. Combining Moving Shipments to the traditional Vehicle Routing Problem is a new contribution to literature.

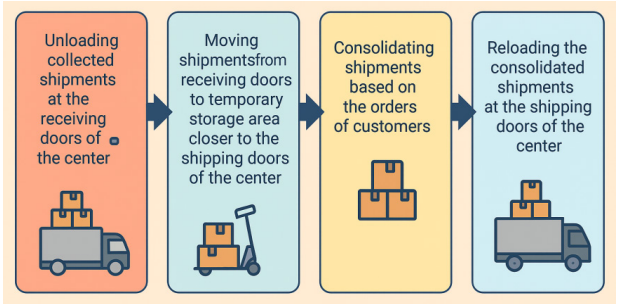


Figure 1: Internal operations at a CDC

Subsequently, scheduling inbound vehicles to receiving doors and outbound vehicles to shipping doors of a CDC based on two different concepts 'arrival time' and 'route quantity' respectively, is a novelty in regards of vehicle scheduling problem. The aim of this research was to develop a mathematical model that integrates the vehicle routing problem and vehicle scheduling problem with CDC to obtain near optimal solutions for the total transportation cost.

Researchers have conducted several studies on vehicle routing problem with cross-docking by applying different approaches. However, the internal operations were not considered in those studies. This study differs from the literature in four-fold. Firstly, the following internal operations in the consolidation process at CDC are taken into consideration: 'Unloading shipments' at the receiving doors, 'Moving shipments' internally and 'Reloading shipments' at the shipping doors at CDC. Secondly, 'Loading shipments' at the pickup process and 'Unloading shipments' at the delivery process are also taken into account. Thirdly, scheduling vehicles by minimizing the 'waiting time' of vehicles based on two different aspects. One aspect is based on the 'arrival time' of inbound vehicles at the pickup process. The other aspect is based on the 'route quantity' of outbound vehicles at the delivery process. Finally, the formulation of the mathematical model of the integrated problem by including aforementioned all three features.

Methodology

Some of the assumptions in the initial study in the literature are relaxed here. Accordingly, a mixed integer quadratic programming model is developed for the integrated problem. The exact solutions to the small-scale instances of the problem are obtained using the Branch-and-Bound algorithm. Furthermore, a meta-heuristic method and also a hybrid method based on the Genetic Algorithm to reach near optimal solutions to large-scale instances of the problem are proposed. Moreover, to attain the best robustness of meta-heuristic algorithms, their parameters have to be estimated. Therefore, as per the parameter design scheme, Taguchi's method, proposed in is incorporated. Furthermore, One-Way Analysis of Variance is employed to determine the most influential parameters of the Genetic Algorithm. The accuracy of the models is tested using the data extracted from the benchmark instances from in the literature. To compare the performances of the solution methods, the Relative Percentage Deviation measure is used.

Results and Discussion

The results reveal the feasibility of the developed model for the integrated problem and these results are compared with the enumeration method. Moreover, the Branch-and-Bound algorithm was able to obtain the exact optimal solution only to the small-scale instances in which the feasible solutions of some of the instances are obtained after more than three hours. Therefore, the exact optimal solution is not computationally efficient to obtain even for the moderately medium size instances. It was observed that the average run time to reach the exact optimal solution increases when the size of the instance increases. The fitted curve to the run time is found to be exponential with the coefficient of determinant, value, as 95%.

It is observed from the average run time that, on average, a near optimal solution to each instance can be reached in nearly 20 seconds even when the size of the instance is 200. It should be emphasized that, though slightly more run time is required to reach a better solution by the hybrid approach, the difference in run time on average is nearly 25 seconds for the largest instance. Therefore, the additional run time consumed to reach a better solution from the hybrid approach than the Genetic Algorithm is not that significant and meta-heuristic based hybrid approach is also considerably a good approach in terms of the run time.

Furthermore, the hybrid approach achieves a more improved solution than that of the meta-heuristic approach. In particular, the average solution of the hybrid approach is much better than the best solution that is produced by the meta-heuristic approach. Moreover, the Relative Percentage Deviation values reveal that, on average, nearly 15% of the improvement in the quality of the solution can be reached by the hybrid approach compared to the meta-heuristic approach.

Conclusion

The results obtained by the Branch-and-Bound algorithm confirm the compatibility of the proposed model. The complexity of the problem in terms of run time is exponential. Thus, when the instance size increases, proportionally the run time to reach the optimal solution also increases. The accuracy of the proposed Genetic Algorithm is more than 94%. Since the Genetic Algorithm is relatively better in performance, the developed model for the problem can be used not only to route the vehicles, but also to schedule the vehicles to the doors of the CDC at the last moment prior to the start of the time horizon. Moreover, the results reveal that, on average, nearly 15% more improvement in the quality of the solution can be reached by the hybrid approach than the Genetic Algorithm approach. Eventually, the hybridized approach is a better approach to reach a near optimal solution than utilizing the Genetic Algorithm approach alone in terms of the rate of convergence. Furthermore, some of the practical implications of impact on cost savings and operational efficiency are also suggested. Also, it recommends managerial implications for the practitioners of cross docking strategy in their supply chain.

Acknowledgement

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INTERPOLATION METHODS AND RADIAL BASIS FUNCTION-FINITE DIFFERENCE METHOD FOR SOLVING GROUNDWATER FLOW EQUATIONS AND CONTAMINANT WATER TRANSPORT EQUATIONS



Dulashini Karunarathna *graduated in 2021 from the Faculty of Science, University of Peradeniya, Sri Lanka with a BSc (Hons) Degree in Mathematics with a First Class. She was placed on the Dean's List and received a University Award for Academic Excellence in recognition of her outstanding academic performance. In 2026, she completed her MPhil Degree in Mathematics from the Postgraduate Institute of Science, University of Peradeniya, Sri Lanka. Currently, she is working as Lecturer (Probationary) at Department of Mathematical Sciences, Faculty of Applied Sciences, Wayamba University of Sri Lanka.*

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Numerical methods are widely used in mathematics, and engineering for interpolation and for solving partial differential equations (PDEs). This study evaluates the Radial Basis Function-Finite Difference (RBF-FD) method against the traditional Radial Basis Function (RBF) approach and demonstrates its superior accuracy and stability using application problems. The central significance of this study lies in introducing a novel and effective framework based on the RBF-FD method for solving a broad class of groundwater flow, heat transport, and contaminant transport problems. Building on this foundation, the study develops a stable and computationally efficient RBF-FD approach for inverse problems, specifically the identification of time-dependent thermal conductivity coefficients in parabolic PDEs. The method achieves high-order convergence, maintains accuracy under noisy boundary conditions, and has been validated across multiple PDE scenarios.

Furthermore, the RBF-FD method is then applied to simulate heat transport in closed geothermal systems in regimes dominated by conduction, intermediate, and convection, showing strong agreement with analytical solutions. An improved RBF-FD framework is introduced further to solve groundwater flow in confined and leaky aquifers under tidal fluctuation, achieving convergence orders of up to four and highly sparse differentiation matrices, indicating significant computational efficiency. Finally, the approach is extended to solve contaminant transport in semi-infinite domains with both constant and oscillatory boundary conditions. The results reveal the strong influence of boundary oscillation characteristics on near-boundary concentration behavior and are validated using available analytical solutions and considering error values of the obtained solutions. Overall, these results show that the effectiveness and accuracy of the RBF-FD approach for solving groundwater flow, heat, and contaminant transport problems.

Methodology

Consider the initial-boundary value problem:

$$\begin{cases} \frac{\partial}{\partial t}\mathrm{u}(\underline{\mathrm{x}},\mathrm{t}) = \mathrm{Lu}(\underline{\mathrm{x}},\mathrm{t}), & \underline{\mathrm{x}} \in \Omega,\ \mathrm{t} \in [0,\ \mathrm{T}], \\ \mathrm{u}(\underline{\mathrm{x}},\mathrm{t}) = \mathrm{g}(\underline{\mathrm{x}},\mathrm{t}), & \underline{\mathrm{x}} \in \partial\Omega,\ \mathrm{t} \in [0,\ \mathrm{T}], \\ \mathrm{u}(\underline{\mathrm{x}},0) = \mathrm{h}(\underline{\mathrm{x}}), & \underline{\mathrm{x}} \in \Omega \end{cases} \tag{1}$$

where *L* is any linear operator. As with the interpolation problems, assume that *u (x,t)* is a linear combination of RBFs and polynomials.

$$u(\underline{x},t) = \sum_{i=1}^{N} \lambda_i \phi(\|\underline{x} - \underline{x}_i\|) + \sum_{k=1}^{M} \mu_i\, p_j(\underline{x}), \tag{2}$$

The equation (2) leads to the system of equations:

$$\begin{bmatrix} A & P \\ P^T & O \end{bmatrix} \begin{bmatrix} \vec{\lambda} \\ \vec{\mu} \end{bmatrix} = \begin{bmatrix} \vec{u} \\ \vec{0} \end{bmatrix} \tag{3}$$

where A is the collocation matrix and P is the Transpose of Vandermonde matrix.

The spatial operator L is applied to equation (2). However, it should be noted that $\vec{\lambda}$ and $\vec{\mu}$ remain unchanged under the action of the operator L. Since the collocation matrix is nonsingular, λ_i and μ_i values can be determined from the equation (3) and subsequently substituted into the system of equations produced by equation (4).

$$Lu\left(\vec{x}_c, t\right) = \left[L\phi_{\vec{x}=\vec{x}_c} \quad LP_{\vec{x}=\vec{x}_c}\right] \begin{bmatrix} \vec{\lambda} \\ \vec{\mu} \end{bmatrix}$$

$$Lu\left(\vec{x}_c, t\right) = \left(\left[L\phi_{\vec{x}=\vec{x}_c} \quad LP_{\vec{x}=\vec{x}_c}\right]_{1\times(n+M)} \begin{bmatrix} A & P \\ P^T & O \end{bmatrix}^{-1}_{(n+M)\times(n+M)} \right)$$

The 1×(n+M) row vector produced by the right-hand side of above equation consists of the operator L's differentiation weights (DM).

Results and Discussion

This study proposed a novel RBF-FD method for approximating both the solutions and time-dependent heat coefficients of parabolic PDEs. The method is validated using six application problems, and Figures 1 and 2 illustrate the numerical solutions obtained for one of these applications.

Furthermore, the RBF-FD approach was employed to solve the groundwater flow equation for both confined and leaky confined aquifer systems. Figure 3 presents the numerical solutions depicting groundwater head fluctuations in these models. The obtained results are validated through convergence analysis and by comparing the numerical solutions with available analytical solutions, with corresponding error measures evaluated to assess accuracy. The Figures 4 and 5 illustrate the p-1 rate of convergence for the approximated solution in confined and leaky confined aquifers.

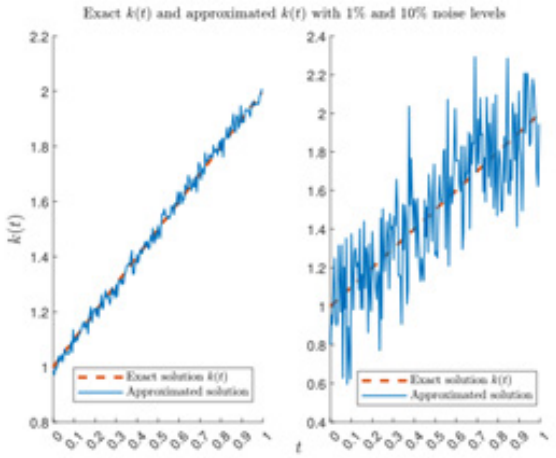


Figure 1: Exact K(t) and approximated K(t) at different noise levels. The left plot has 1% noise, and the right plot has 10% noise

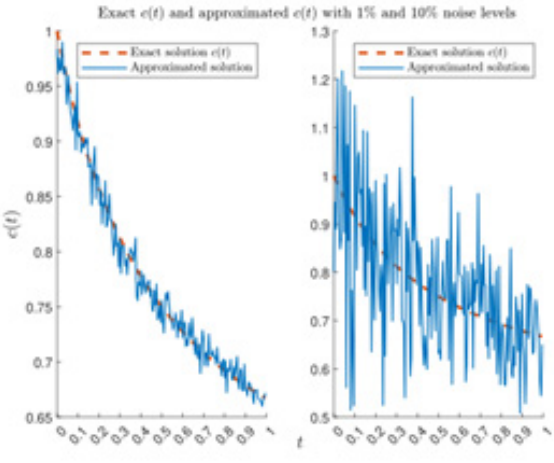


Figure 2: Exact c(t) and approximated c(t) at different noise levels. The left plot has 1% noise, and the right plot has 10% noise

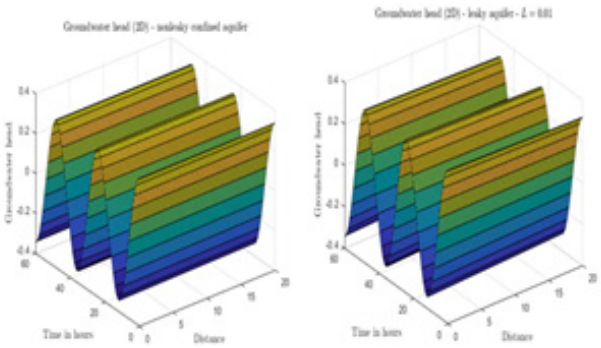


Figure 3: Left figure illustrates the groundwater head fluctuation in confined aquifer and right-side figure in leaky confined aquifer with specific leakage L = 0.01 per day

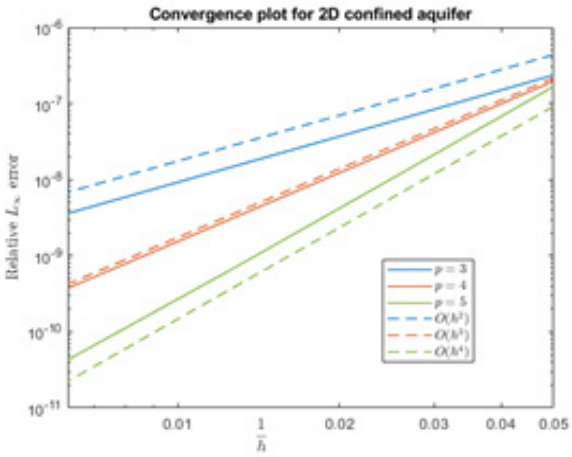


Figure 4: Convergence analysis was performed for the approximated numerical solution in a confined aquifer system

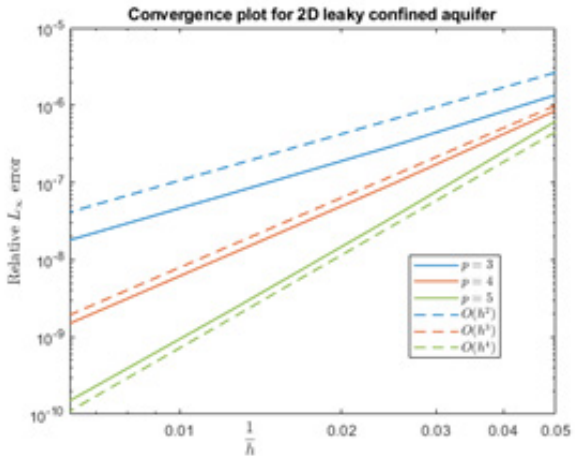


Figure 5: Convergence analysis was performed for the approximated numerical solution in the leaky confined aquifer system

Finally, the numerical approach is extended to solve one- and two-dimensional contaminant transport problems. Figure 6 depicts the obtained numerical and analytical results for a two-dimensional pollution problem. The error values presented in Table 1 validate the accuracy of the RBF-FD method.

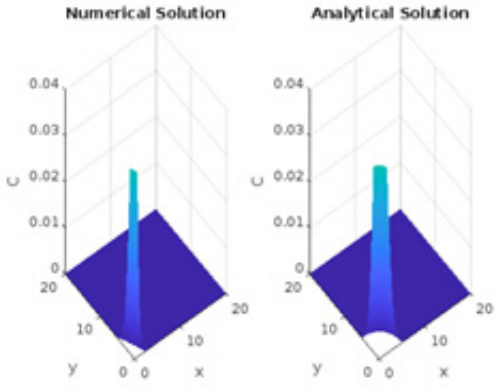


Figure 6: Numerical and analytical solution for the diffusion coefficient $D_x = D_y = 1$, illustrating the concentration distribution after 1 hour (T = 1) of groundwater pollution

Table 1. Error values of the numerical solution obtained by comparing it with the analytical solution for varying diffusion coefficients, time steps, and numbers of nodes

Diffusion Coefficient and Time	Root Mean Square Error	
	100×100 Nodes (10^{-3})	200×200 Nodes (10^{-3})
$D_x = D_y = 1$, T = 1	3.547831	3.357426
$D_x = D_y = 1$, T = 2	2.941006	2.818583
$D_x = D_y = 2$, T = 1	2.386863	2.294878
$D_x = D_y = 2$, T = 2	1.985542	1.927725

Conclusion

The RBF-FD approach demonstrates strong capability as an effective numerical method for solving a wide range of mathematical and engineering problems. Its strength lies in its high accuracy, computational efficiency, and flexibility in handling complex geometries and scattered node distributions. These characteristics make it particularly suitable for solving PDEs across various scientific and engineering applications. Future research may focus on improving parameter optimization techniques and extending the method to more complex real-world systems and large-scale simulations.

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EXPLORATIONS IN ALGEBRAIC GRAPH THEORY: FACTORIZATION, PARTITION, COLORING, AND THEIR APPLICATIONS



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Graphs arise naturally in many real-world systems, from communication networks and transportation systems to biological interactions and data structures. As modern science increasingly relies on modeling complex relationships, graph theory has become a fundamental mathematical framework for understanding connectivity, structure, and optimization in such systems. Among the many areas of graph theory, the study of graph factorizations plays a crucial role in decomposing complex networks into simpler, well-structured components, enabling both theoretical insights and practical applications.

A factor of a graph is a spanning subgraph that preserves certain structural properties, while a factorization represents a decomposition of a graph into edge-disjoint factors. Over the past century, significant progress has been made in understanding the existence and construction of such factorizations, beginning with classical results such as Petersen's theorem and Tutte's 1-factor theorem. Despite these advances, many problems related to factorization in complex graph classes, particularly multipartite graphs, remain open and continue to attract considerable research attention.

In parallel, other branches of algebraic graph theory, such as graph reconstruction, graph coloring, and graph labeling, have developed into active research areas with deep theoretical significance and wide-ranging applications. The graph reconstruction problem, introduced in the twentieth century, seeks to determine whether a graph can be uniquely identified from its substructures and remains one of the most challenging open problems in graph theory. Similarly, chromatic polynomials provide powerful tools for understanding graph coloring properties, while graph labeling techniques have found applications in communication systems, coding theory, and network design.

Beyond theoretical developments, graph theory has also emerged as a powerful tool in modern cryptography. The need for secure communication in digital systems has led to the exploration of mathematical structures for designing encryption algorithms. Graph-based cryptographic methods offer a promising alternative by combining combinatorial structures with number-theoretic techniques to produce secure and efficient encryption schemes.

Motivated by these developments, this study aims to explore both the theoretical and applied aspects of algebraic graph theory. The research focuses on the factorization of complete multipartite graphs, the reconstruction of specific graph classes, and the development of chromatic polynomials for newly introduced graph structures. In addition, the study

investigates category-theoretic properties of graphs and proposes novel encryption and decryption algorithms based on graph labeling and multipartite graph structures. Overall, this work demonstrates the versatility of graph theory as both a theoretical discipline and a practical tool, highlighting its potential to address complex problems in mathematics, computer science, and information security.

Methodology

This study adopts a comprehensive approach that integrates theoretical analysis, combinatorial reasoning, and computational implementation to investigate key problems in algebraic graph theory and their applications. The methodology combines combinatorial techniques, inductive reasoning, and computational implementation to investigate structural and algorithmic problems in graph theory.

From a theoretical standpoint, the study employs degree-based factorization techniques and multidimensional induction to analyze complete multipartite graphs. In particular, general results concerning the existence and enumeration of 1-factors are derived through structured combinatorial arguments. These methods allow for the systematic extension of classical results to more complex graph structures, especially those with repeated partition sizes. Furthermore, constructive proof techniques are used in the context of graph reconstruction, where graphs are recovered from vertex-deleted subgraphs (cards). This approach enables the identification of key invariants such as degree sequences, adjacency relations, and edge distributions, which collectively determine the original graph structure.

In addition, the study explores graph coloring through the derivation of chromatic polynomials, utilizing recursive techniques such as the Deletion–Contraction theorem. A novel class of graphs, referred to as *scorpion graphs*, is introduced and analyzed within this framework, extending the scope of algebraic graph theory. The research also incorporates concepts from category theory, defining a smash product for pointed simple reflexive graphs and examining its relationship with graph homomorphisms, thereby providing a deeper structural interpretation of graph operations.

From an applied perspective, the research integrates number theory with graph theory to develop innovative cryptographic frameworks. These methods are based on modular arithmetic, prime factorization, and structured graph constructions, including multipartite and path graphs, to encode and encrypt information. A second encryption scheme is developed using Skolem graceful labeling, where graph labeling techniques are used to construct a polyalphabetic cipher with enhanced structural flexibility. To support these developments, computational tools (Python programming) are utilized to implement algorithms, verify theoretical results, and generate graphical representations of labeled and encrypted graph structures. This combination of theoretical rigor and computational validation ensures both mathematical correctness and practical applicability.

Results and Discussion

The findings of this study demonstrate significant contributions to both the theoretical development and practical applications of algebraic graph theory, highlighting the effectiveness of combining combinatorial reasoning with computational and algorithmic approaches.

A major theoretical contribution of this work is the derivation of a general formula for the number of 1-factors in the factorization of complete multipartite graphs with an even number of partite sets (Table 1). The derived formula extends classical factorization theory and provides a systematic framework for analyzing highly structured graph classes. The use of multidimensional induction allows the generalization of results across different parameter values, making the approach both flexible and scalable. These findings contribute to a deeper understanding of graph decomposition and its structural properties.

Table 1. Examples of 1-factors in the factorization of complete multipartite graphs of $K_{m,\ldots,m}$

When $m = 3$ and $l = 1$	Number of 1-factors
$K_{3,3}$ 	
When $m = 2$ and $l = 2$	**Number of 1-factors**
$K_{2,2,2,2}$ 	

In addition to factorization, the study presents a constructive method for the reconstruction of wheel graphs using vertex-deleted subgraphs. By examining properties such as degree sequences, number of edges, and adjacency relationships within the deck of cards, the original graph can be uniquely determined. This result contributes to the ongoing study of the graph reconstruction problem and demonstrates how global graph properties can be inferred from partial structural information.

The research further introduces a new class of graphs, known as scorpion graphs, and derives their chromatic polynomial using combinatorial techniques. This result extends existing knowledge in graph coloring and demonstrates the effectiveness of recursive methods, such as the Deletion–Contraction theorem, in analyzing

complex graph structures. The introduction of scorpion graphs represents a novel theoretical contribution and provides new opportunities for further research in algebraic graph theory.

From a structural perspective, the study also establishes a duality between smash products and graph homomorphisms within the framework of pointed simple reflexive graphs. This result provides a category-theoretic interpretation of graph operations and suggests deeper algebraic structures underlying graph theory. Although abstract, this contribution lays the foundation for future work in categorical graph theory. From an applied standpoint, the research develops a novel cryptographic system based on multipartite graph structures. In this approach, plaintext is transformed into ciphertext represented as a weighted multipartite graph using modular arithmetic and prime-based encoding. This method significantly increases the structural complexity of the encrypted data, making it more secure and resistant to conventional cryptographic attacks.

In addition, a second encryption method is introduced using Skolem graceful labeling, where graph labeling techniques are used to construct a polyalphabetic cipher. The proposed cryptographic framework demonstrates the flexibility of graph-based cryptographic systems and highlights the potential of combining combinatorial structures with classical encryption methods.

Finally, computational analysis reveals that centerless double wheel (CDW) graphs do not admit prime labeling when the number of vertices is odd, while valid labeling exists for even cases. These findings are verified through Python-based simulations and matrix representations, providing strong computational support for the theoretical results.

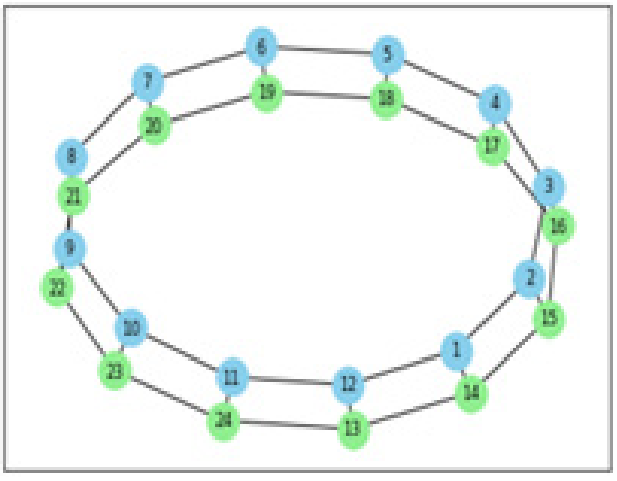


Figure 1: The graph CDW_{24} with the prime labeling (n=12 and n+1=13 is prime)

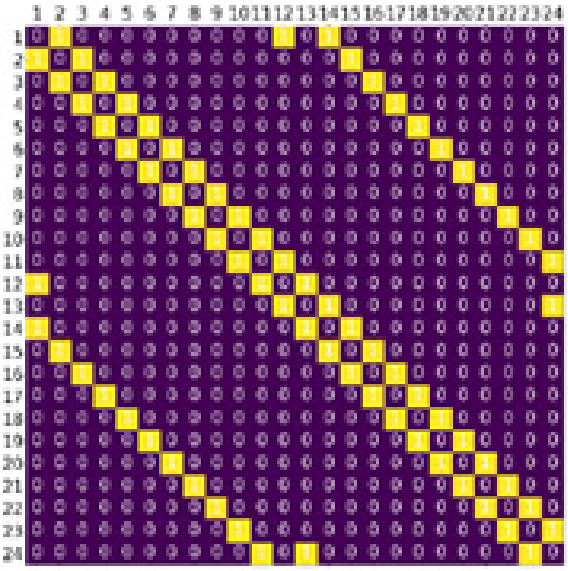


Figure 2: The matrix representation for CDW_{24} by representing the gcd values of adjacent vertices

Overall, the results illustrate the powerful interplay between graph theory, combinatorics, and cryptography, demonstrating how abstract mathematical concepts can be effectively applied to real-world problems such as secure communication and algorithm design.

Conclusion

This study provides a comprehensive exploration of algebraic graph theory by integrating theoretical developments with practical applications. Significant contributions include the derivation of a general formula for determining the number of 1-factors in complete multipartite graphs using combinatorial methods and multidimensional induction, the successful reconstruction of wheel graphs from vertex-deleted subgraphs, and the introduction of a new class of graphs known as scorpion graphs with their corresponding chromatic polynomials. In addition, the research establishes a category-theoretic framework through the development of a smash product and its duality with graph homomorphisms, offering deeper structural insights into graph theory. From an applied perspective, the study demonstrates the effectiveness of graph-based cryptographic systems by developing novel encryption algorithms using multipartite graphs and graph labeling techniques. Computational validation further strengthens the theoretical findings, particularly in the study of prime labeling for specific graph classes. Overall, this work highlights the versatility of graph theory as both a powerful mathematical framework and a practical tool for applications such as secure communication, while also opening avenues for future research in graph factorizations, labeling methods, and cryptographic design.

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INVESTIGATION OF GRAPHITE/GRAPHENE AS BACK-CONTACT MATERIAL FOR THIN FILM SOLAR CELLS



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Sri Lanka produces high-quality natural vein graphite with exceptional crystallinity and carbon purity (95-98%). The needle platy vein graphite is valuable for advanced material applications due to its structured properties. There is increasing interest in transforming this graphite into graphene-based materials, such as reduced graphene oxide (RGO), which have diverse applications in energy storage, sensing, conductive coatings, and photovoltaics. The local availability of high-purity graphite allows Sri Lanka to develop cost-effective graphene derivatives, benefiting the economy.

The increasing demand for sustainable energy has driven research into renewable energy systems, particularly solar photovoltaics. CdTe-based thin-film solar cells are prominent due to their high absorption coefficient, low material usage, and cost-effectiveness.

The performance and stability of CdTe solar cells are heavily influenced by back-contact materials. An ideal back contact should have high conductivity, chemical stability, low resistance, and compatibility with p-type CdTe. While metallic contacts such as Cu/Au offer excellent performance, they are costly and prone to stability issues. Carbon-based materials, especially graphene-derived ones, emerge as a promising alternative due to their superior conductivity, mechanical flexibility, chemical stability, and low production costs.

Reduced graphene oxide has gained attention as a potential back contact material due to its tunable electrical properties and large-scale processability. However, the electrical performance of RGO films strongly depends on synthesis conditions and thin-film deposition parameters. Therefore, optimizing the synthesis and deposition processes is essential to improving the quality

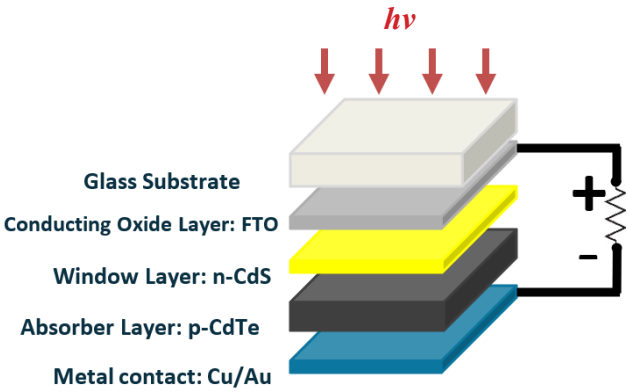


Figure 1: A schematic diagram of CdS/CdTe thin-film solar cell

of RGO films intended for photovoltaic applications. This work demonstrates the potential of value-added Sri Lankan natural graphite as a functional material for thin-film applications. The study also contributes to the development of low-cost, sustainable back-contact materials for CdTe-based solar cells while promoting the advanced utilization of Sri Lanka's natural graphite resources.

Methodology

Graphene oxide (GO) was synthesized using the modified Hummers method and subsequently reduced using L-ascorbic acid to obtain RGO powder. The reduction duration was optimized to minimize structural disorder and improve electrical properties. RGO thin films were deposited using the Atomized Spray Pyrolysis Deposition (ASPD) technique. Substrate and annealing temperatures were systematically varied to optimize film conductivity and microstructural quality. Electrical, structural, and morphological characterizations were performed.

Finally, the optimized RGO films were used as back-contact materials in CdS/CdTe thin-film solar cells fabricated via close-spaced sublimation. The photovoltaic performance of RGO back contacts was compared with that of conventional Cu/Au contacts.

Results and Discussion

The study explored the use of reduced graphene oxide (RGO), derived from Sri Lankan natural vein graphite, as an alternative back contact material for CdS/CdTe thin-film solar cells. It highlighted the suitability of Sri Lankan needle platy-vein graphite for its high purity and crystallinity. GO was synthesized via the modified Hummers method and then reduced with L-ascorbic acid to obtain RGO. The optimal reduction time of 1.5 hours resulted in RGO with improved graphitic ordering, fewer oxygen-containing functional groups, and enhanced structural quality.

The deposition of RGO thin films using the ASPD technique is an effective, scalable, and low-cost method for producing uniform films with controlled morphology. The study found that substrate temperature (optimal at 150 °C) and annealing temperature (optimal at 330 °C) significantly affect electrical and structural properties of the film. Under these conditions, the RGO films exhibited improved surface morphology, higher crystallinity, a lowest carbon-to-oxygen atomic ratio, and maximum electrical conductivity of 16.8 S cm^{-1}. Analyses using Raman spectroscopy, GIXRD, and SEM confirmed that thermal treatment enhanced the graphitic lattice and reduced structural defects in the RGO films.

The electrical characterization of optimized RGO films using Van der Pauw and Hall effect methods revealed improved carrier mobility and concentration, which are crucial for efficient charge transport in solar cells. The enhanced conductivity and microstructural properties indicate the suitability of RGO thin films for electronic and photovoltaic applications. Additionally, the ASPD technique minimized precursor waste and produced highly uniform films, demonstrating its potential for scalable, economical thin-film production.

The study compared CdS/CdTe thin-film solar cells with RGO as the back contact to those with traditional Cu/Au contacts. RGO solar cells had a lower conversion efficiency of 0.54%, while Cu/Au achieved 9.14%. Despite this, RGO exhibited promising photovoltaic behavior and comparable quantum efficiency in the visible region. The lower performance was attributed to rollover behavior in the J-V characteristics, driven by back-contact barriers and current saturation. The findings suggest that RGO is a viable, low-cost, and sustainable back-contact material, with potential for improvement through enhanced RGO quality and strategies to improve charge transport and reduce resistance.

Reducing defect density in RGO powders and thin films enhances solar cell efficiency by improving conductivity and carrier transport. Incorporating copper nanowires to RGO further enhances electrical connectivity and reduces Schottky barrier effects by forming a stable CuTe interfacial layer at the CdTe/back contact interface.

Conclusion

This study investigated RGO synthesized from Sri Lankan natural graphite as a back contact material for CdS/CdTe thin-film solar cells. RGO was synthesized using the modified Hummers method and deposited by the ASPD technique. Optimized films deposited at 150 °C and annealed at 330 °C showed improved conductivity and structural quality. Although CdS/CdTe thin-film solar cells with RGO back contact exhibited lower efficiency than Cu/Au contacts, the results demonstrated the potential of RGO as a low-cost, sustainable alternative back-contact material.

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RECYCLABLE PARAMAGNETIC MgO NANOADSORBENT FOR EFFICIENT REMOVAL OF HEAVY METAL IONS, PHOSPHATE IONS, AND ORGANIC POLLUTANTS FROM WASTEWATER



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Water pollution is one of the most pressing global environmental challenges of our time. Over 3.5 million people die annually from waterborne diseases, and less than 1% of freshwater on Earth is accessible for safe drinking, with demand projected to increase by a further 25% in the coming decades. Heavy metals such as lead (Pb), cadmium (Cd), and mercury (Hg) discharged from mining, tanneries, battery plants, and chemical factories together with commercial cationic dyes such as methylene blue (MB) and phosphate ions, accumulate in water bodies and pose severe risks to human health, affecting the digestive, nervous, reproductive, and renal systems. Dye compounds are additionally mutagenic and carcinogenic. Conventional remediation approaches, including chemical precipitation, coagulation, and membrane filtration, are often expensive, energy-intensive, and produce hazardous secondary waste streams. Adsorption has emerged as the most widely adopted alternative owing to its simplicity, efficiency, and cost-effectiveness. Among adsorbents, magnesium oxide (MgO) nanoparticles are particularly attractive: their point of zero charge (pH_{pzc} = 12.4) generates strong electrostatic interactions with contaminants across a wide pH range, and their high surface area and porosity make them effective for both heavy metals and organic dyes outperforming common alternatives such as ZnO, TiO_2, and Al_2O_3. A persistent practical limitation of MgO nanoparticles, however, is the difficulty of recovering nanosized particles from treated water, which risks secondary contamination. Incorporating a magnetic phase into the adsorbent framework resolves this problem: the composite can be retrieved efficiently with an external magnet, regenerated, and reused properties essential for practical, cost-effective, large-scale water treatment.

This MPhil study investigated the development, characterisation, and adsorption performance of two novel magnetically recoverable, recyclable MgO-based nanocomposites: (i) nano zero-valent iron-coated MgO (nZVI-MgO), a dual-function material combining adsorption and photocatalytic activity, synthesised via aqueous-phase iron reduction and oleic acid surface modification; and (ii) natural magnetite-coated MgO (NMCMO), an eco-friendly composite prepared by ball-milling naturally sourced magnetite from Buttala, Sri Lanka with MgO a lower-cost, sustainable route that avoids synthetic magnetic precursors and makes use of a locally available natural resource. Both materials were evaluated for the removal of Pb(II), Cd(II), Hg(II), MB, and phosphate ions from aqueous solutions under systematically optimized conditions.

Methodology

Two magnetically recoverable MgO-based nanocomposites, namely nZVI–MgO and NMCMO, were synthesised and evaluated in this study. The nZVI–MgO was synthesised via chemical reduction followed by MgO shell coating. The nZVI was produced by reducing $FeCl_3 \cdot 6H_2O$ with $NaBH_4$ under a nitrogen atmosphere in deoxygenated water. The resulting nZVI particles were magnetically separated, washed, and surface-stabilised with oleic acid to suppress oxidation and aggregation. MgO was subsequently precipitated onto the nZVI surface by introducing $MgCl_2 \cdot 6H_2O$ followed by controlled addition of ammonia solution, yielding a core–shell-type composite. The product was magnetically separated, washed, vacuum-dried, and calcined under an argon atmosphere to obtain the final nZVI–MgO nanocomposite.

The NMCMO was synthesised using naturally occurring magnetite sourced from Buttala, Sri Lanka, a deliberate choice that eliminates the need for synthetic iron precursors, reducing both cost and synthetic complexity. The ground magnetite was surface modified with stearic acid to improve dispersion, then dispersed in $MgCl_2$ solution. The controlled addition of ammonia facilitated the precipitation of MgO onto the magnetite surface. The product was magnetically separated, washed, dried, and calcined to yield the final NMCMO composite. Compared to nZVI–MgO, this route is simpler, more cost-effective, and scalable, while retaining strong magnetic recoverability.

Both composites were comprehensively characterised using XRD, SEM, TEM, EDS, FTIR, XPS, BET surface area analysis, VSM, and particle size analyzer. The Pb(II), Cd(II), and Hg(II) concentrations were quantified by atomic absorption spectrophotometry (AAS), while MB was monitored by UV-visible spectrophotometry. Adsorption performance was assessed through systematic batch experiments optimising adsorbent dosage, initial pollutant concentration, solution pH, and contact time. Kinetic data were fitted to pseudo-first-order, pseudo-second-order, liquid-film diffusion, and intra-particle diffusion models; equilibrium data were described using Langmuir, Freundlich, and Temkin isotherm models. Photocatalytic MB degradation was conducted under a 125 W high-pressure mercury vapour lamp and monitored spectrophotometrically at 654 nm. Recyclability of nZVI–MgO was assessed via acid-assisted desorption followed by magnetic recovery and calcination, while NMCMO regeneration employed an innovative dry-ice (solid CO_2) carbonation-assisted protocol followed by thermal treatment.

Results and Discussion

The results collectively demonstrate that both nZVI–MgO and NMCMO possess well-defined nanostructures, multi-mechanism adsorption behaviour, and practical recyclability, establishing them as high-performance candidates for real-world wastewater remediation. XRD analysis confirmed the successful formation of both composites, identifying α-Fe and MgO (periclase) in nZVI-MgO, and Fe_3O_4, Fe_2O_3, and MgO in NMCMO. SEM and TEM imaging of nZVI-MgO revealed a well-defined core–shell nanoarchitecture a dense Fe core encapsulated within a protective MgO shell that simultaneously maximizes reactive surface sites, suppresses nZVI oxidation, and prevents particle aggregation. This structural design directly underpins the material's outstanding remediation performance. BET analysis confirmed the mesoporous character of nZVI-MgO (surface area: 105.08 $m^2 \cdot g^{-1}$), while NMCMO exhibited a heterogeneous morphology of rod-like MgO interspersed with spongy spherical magnetite. Both composites retained high magnetic saturation 59.63 $emu \cdot g^{-1}$ (nZVI-MgO) and 32.02 $emu \cdot g^{-1}$ (NMCMO) enabling efficient magnetic separation after treatment. XPS confirmed surface complexation, ion exchange, and Mg-O-Pb chemical bonding as key adsorption mechanisms, while post-adsorption XRD patterns revealed newly formed metal-containing phases ($Pb_3(CO_3)_2(OH)_2$, $Cd(OH)_2$, HgO, and others), providing direct evidence that pollutant removal proceeds through a multi-mechanism framework rather than a single pathway.

The nZVI-MgO demonstrated exceptional Pb(II) removal, achieving an adsorption capacity of 3418.37 mg g^{-1} with 97.67% removal efficiency. For methylene blue (MB), a capacity of 2246.73 mg g^{-1} was attained. Chemisorption was confirmed as the dominant mechanism for both pollutants, with heterogeneous multilayer adsorption behaviour consistent across all isotherm data. Beyond adsorption, nZVI-MgO uniquely demonstrated photocatalytic MB degradation: upon light irradiation, MgO generates reactive oxygen species, superoxide radicals ($O_2 \bullet^-$) and hydroxyl radicals (•OH) that mineralise MB completely to CO_2 and H_2O. An optimum photodegradation efficiency of 90.69% was achieved within 120 minutes under a 125 W mercury lamp, following first-order kinetics. This dual functionality, high-capacity adsorption combined with photocatalytic mineralisation distinguishes nZVI-MgO from conventional single-mode remediation materials. Regeneration was highly effective: 95.4% Pb(II) desorption was achieved with no significant activity loss across the first two cycles, while photocatalytic efficiency was maintained at 75.19% in the second cycle.

The NMCMO demonstrated remarkable versatility, simultaneously remediating multiple priority pollutants with adsorption capacities that substantially exceed previously reported MgO-based adsorbents. Pb(II) removal was most efficient (3939.69 $mg \cdot g^{-1}$; 98.49%), followed by MB (2826.15 $mg \cdot g^{-1}$; 94.2%), Cd(II) (2285.04 $mg \cdot g^{-1}$; 91.4%), and Hg(II) (1748.05 $mg \cdot g^{-1}$; 87.4%). Chemisorption governed all four systems, with heterogeneous multilayer adsorption confirmed

across all heavy metal and dye systems. Phosphate removal followed a mechanistically distinct pathway, achieving 1256.62 $mg \cdot g^{-1}$ with 83.78% efficiency through monolayer adsorption on a homogeneous surface-corroborated by the post-adsorption formation of hydroxyapatite and a distinctive elongated leaf-like surface restructuring observed by SEM. NMCMO was regenerated using an innovative dry-ice carbonation-assisted protocol, which induced phase transformation and concurrent Pb(II) desorption, achieving 87.10% desorption efficiency offering a mechanistically elegant and environmentally preferable alternative to conventional acid-based regeneration.

Conclusion

This study establishes nZVI–MgO and NMCMO as high-performance, magnetically recoverable nanocomposites for the simultaneous removal of heavy metals (Pb, Cd, Hg), MB, and phosphate from aqueous systems, achieving adsorption capacities that substantially surpass previously reported MgO-based materials. Both composites operate through co-operative multi-mechanism pathways surface complexation, ion exchange, and precipitation providing robust performance across diverse pollutant classes. The superparamagnetic character of both materials enables simple magnetic recovery after use, while their demonstrated recyclability supports cost-effective, low-waste operation. The nZVI–MgO further extends its utility through photocatalytic MB mineralisation, and NMCMO synthesised from naturally sourced magnetite offers a sustainable and scalable production route. Together, these materials present a compelling platform for integration into practical wastewater treatment systems, including fixed-bed columns and hybrid adsorption photocatalysis processes.

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ASSOCIATION BETWEEN BMI VARIATIONS AND AORTO-SUPERIOR MESENTERIC ARTERY: A CT-BASED STUDY OF A SRI LANKAN COHORT



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The abdominal aorta is the primary arterial trunk descending through the retroperitoneal cavity, giving rise to vital visceral branches that supply oxygenated blood to the gastrointestinal tract. Among these major branches, the Superior Mesenteric Artery (SMA) branches off anteriorly from the abdominal aorta typically at the level of the first lumbar (L1) vertebra. The anatomical path of the SMA is highly unique and critical: it courses downwards and forwards, passing directly in front of the left renal vein and the third part of the duodenum. In a healthy individual, this restricted space is safely maintained by a specialized cushion of retroperitoneal and mesenteric fat. This fat pad acts as a natural physical buffer, preventing the SMA from compressing the structures lying underneath it.

When this protective fat pad is rapidly depleted, due to severe weight loss, wasting conditions, or inherently low body mass, the space between the vessels narrows significantly. This can result in the mechanical entrapment and obstruction of the third part of the duodenum, a rare clinical condition known as Superior Mesenteric Artery Syndrome (SMAS). Patients suffering from SMAS experience debilitating symptoms, including severe postprandial abdominal pain, early satiety, nausea, and chronic vomiting. A concurrent compression can also occur at the same vascular intersection, trapping the left renal vein. This secondary impairment is known as Nutcracker Syndrome (NCS), which manifests as flank pain and hematuria.

In clinical radiology, evaluating these syndromes relies heavily on measuring two precise spatial parameters: the Aorto-Mesenteric Angle (AMA), which reflects the angular origin of the branch, and the Aorto-Mesenteric Distance (AMD), which measures the linear gap between the vessels. While standard international radiological cutoff points exist, universal reference thresholds are often inaccurate because body shapes and fat distributions vary dramatically across different ethnic groups. Prior to this study, normative baseline values for these vascular structures were completely lacking for the Sri Lankan population, leading to a high risk of clinical misinterpretation or over-diagnosis in leaner individuals.

Methodology

This cross-sectional clinical study evaluated a total cohort of 120 adult patients who underwent diagnostic abdomen and pelvis examinations at the Department of Radiology, Base Hospital Karawanella, Sri Lanka. To capture highly accurate, real-time vascular anatomy, all patients underwent Contrast-Enhanced Computed

Tomography (CECT) scans using a standardized diagnostic protocol. High-resolution multi-slice imaging datasets were acquired during the peak arterial enhancement phase.

Advanced digital post-processing software was utilized to perform Multi-Planar Reconstructions (MPR). This allowed the primary investigator to view the abdominal vasculature simultaneously in the axial and sagittal planes. The Aorto-Mesenteric Angle (AMA) was calculated in degrees on sagittal and sagittal oblique slices by tracing the longitudinal axes of the abdominal aorta and the proximal SMA. The Aorto-Mesenteric Distance (AMD) was measured in millimeters on corresponding axial slices as the shortest linear distance between the posterior border of the SMA and the anterior wall of the aorta at the level where it crosses the duodenum.

Participants were strictly stratified into five distinct body mass categories based on the localized guidelines set by the Nutrition Division of the Ministry of Health, Sri Lanka, which are optimized for South Asian phenotypes: Underweight ($\leq$ 18.5 kg m^{-2}). Normal Weight (18.5 kg m^{-2} – 22.9 kg m^{-2}), Risk-to-Overweight (23 kg m^{-2} – 24.9 kg m^{-2}), Overweight (25 kg m^{-2} – 29.9 kg m^{-2}) and Obese. Statistical correlation profiles between body mass and vascular parameters were calculated using Spearman's Rank Correlation (ρ). Variations across the five weight tiers were evaluated using the non-parametric Kruskal-Wallis H test, followed by Dunn's post-hoc pairwise comparisons to isolate specific inter-group differences. Institutional ethical approval was officially secured from the Committee for Ethical clearance of the Postgraduate Institute of Science, University of Peradeniya.

Results and Discussion

The investigation successfully established the first normative baseline values for an adult Sri Lankan cohort, yielding a collective mean Aorto-Mesenteric Angle (AMA) of 49.83 ± 19.36º and a mean Aorto-Mesenteric Distance (AMD) of 13.69 ± 7.21 mm.

When evaluating data across the body mass spectrum, several major scientific insights were revealed:

The Adiposity Buffer Effect: A statistically significant, positive correlation was confirmed between Body Mass Index (BMI) and the linear gap distance (AMD) (ρ = 0.281, p = 0.0019). This provides clear empirical proof that overall body mass directly influences the thickness of the protective internal retroperitoneal fat cushion. A positive but weaker correlation was observed between BMI and the branching angle (AMA) (ρ = 0.222, p = 0.0150).

Dynamic Distance vs. Static Angle: The Kruskal-Wallis analysis proved that the linear distance (AMD) is a highly dynamic structural feature across different weight categories (p = 0.0038). The median AMD expanded substantially from 10.15 mm in underweight individuals up to a wide 24.20 mm within the obese cohort. Conversely, the vascular branching angle (AMA) demonstrated structural stability, showing no statistically significant variations across the distinct weight groups (p = 0.280). This indicates that while the initial branching angle is largely a fixed, genetically determined feature of an individual's vascular anatomy, the actual physical distance between the vessels fluctuates dramatically based on fat accumulation or depletion.

The Asymptomatic Risk Continuum: A major finding of this study was that 20% (1 in 5) of this completely asymptomatic, healthy Sri Lankan cohort met the conventional international radiological risk criteria for duodenal compression (defined as an AMD $\leq$ 8 mm). The prevalence of this narrow structural variant was highest within the Risk-to-Overweight (28.6%) and Underweight (22.5%) categories, whereas the Obese cohort demonstrated a 0% risk prevalence. This highlights that structural vascular narrowing is a continuous anatomic feature rather than an absolute defect, proving that radiological narrowing alone is a necessary but insufficient factor for diagnosing clinical SMAS.

Conclusion

This research provides essential, locally derived reference criteria that are vital for accurate radiological interpretations in South Asia. By demonstrating that an AMD $\leq$ 8 mm is frequently present in a large percentage of healthy, asymptomatic individuals, this study prevents the clinical over-diagnosis and unnecessary surgical management of vascular compression syndromes in lean individuals. Furthermore, because the linear distance acts as a highly sensitive indicator of body mass changes compared to the branching angle, these findings provide a strong scientific foundation for utilizing non-invasive nutritional rehabilitation as the primary conservative treatment strategy to naturally rebuild the retroperitoneal fat buffer and resolve compression symptoms.

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SYSTEMATIC STUDY OF GENUS *Salacia* L. (CELASTRACEAE) IN SRI LANKA: AN INTEGRATED APPROACH



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Salacia L. (Celastraceae; order Celastrales) comprises approximately 200 species of woody lianas and scandent or occasionally erect shrubs distributed throughout tropical regions of India, Sri Lanka, Myanmar, Malaysia, the Solomon Islands, and Africa. Four *Salacia* species have been reported from Sri Lanka; *S. chinensis* L., *S. diandra* Thw., *S. oblonga* Wall. Ex Wight & Arn. (Himbutu) and *S. reticulata* Wight. (Kothala himbutu). *Salacia diandra* is considered as an endemic species to Sri Lanka. A fifth species, *S. acuminatissima* Kosterm., later reported in the National Red List of Flora and Fauna (2012) based on specimens from the Sinharaja Forest Reserve, was subsequently synonymised under *S. diandra*, in the 2020 update, consistent with Wadhwa's earlier taxonomic treatment. During the National Red Listing assessments conducted in 2012 and 2020, *S. reticulata*, *S. oblonga*, *S. acuminatissima*, and *S. diandra* were classified as Endangered (EN), while *S. chinensis* was categorized as Near Threatened (NT).

Salacia species are rich in unique phenolic compounds, such as salacinol and kotanalol, widely used in Ayurvedic treatments for managing high blood sugar. High market demand has led to unsustainable harvesting practices, including stem extraction and removal of mature stems for medicinal products, threatening natural populations. Taxonomic identification within the genus is challenging due to overlapping vegetative characteristics and limited, seasonal flowering. In Sri Lanka, most *Salacia* species are classified as Endangered, highlighting the need for accurate species delimitation. In particular, the taxonomic status of *S. acuminatissima* remains uncertain.

This study addresses taxonomic ambiguities in *Salacia* by integrating morphometrics, wood anatomy, chemotaxonomy, and molecular phylogeny. It focuses on delimiting five Sri Lankan species, with particular emphasis on resolving the distinction between the closely related *S. acuminatissima* and *S. diandra*. Additionally, the taxonomic placement of Sri Lankan *Salacia* is evaluated in a broader context through comparisons with species from India, Thailand, and Australia using GenBank sequences and published data.

Taxonomic delimitation and species limits of Sri Lankan *Salacia* species:

To evaluate species boundaries, initially a morphometric analysis was conducted using vegetative and leaf anatomical characteristics. Separate cluster analyses were performed for quantitative wood anatomical features and secondary metabolite data of *Salacia*. Finally, phylogenetic analysis based on molecular sequence data was carried out to further resolve species relationships and delineate boundaries.

Morphometric analysis was conducted on 98 populations. Due to species rarity and seasonal flowering, only vegetative and leaf anatomical characters were analyzed, comprising 22 qualitative and 41 quantitative traits. Cluster analysis, Principal Component Analysis (PCA), and Principal Coordinate Analysis (PCoA) (Figure 1 and 2) consistently resolved four phenetic groups: *S. chinensis*, *S. oblonga*, *S. reticulata*, and *S. diandra*. The results do not support the recognition of *S. acuminatissima* as a distinct species; instead, it forms a sub-cluster within *S. diandra* without diagnostic vegetative or leaf anatomical differentiation. Wood anatomical and secondary metabolite analyses were also ineffective in delimiting species boundaries, likely due to environmental influences and high intra-genus similarity.

Molecular analyses based on ITS and *psb*A–*trn*H sequences revealed low genetic divergence among the five Sri Lankan *Salacia* species (pairwise distances: 0.01–0.07), with zero distance between *S. diandra* and *S. acuminatissima,* confirming their conspecific status. Phylogenetic reconstruction recovered Sri Lankan *Salacia* as a distinct monophyletic group, separate from other taxa in GenBank, and divided into two major subclades. Consistent clustering of *S. acuminatissima* and *S. diandra* across analyses further supports their treatment as a single species, whereas *S. chinensis, S. reticulata*, and *S. oblonga* are clearly resolved as distinct lineages.

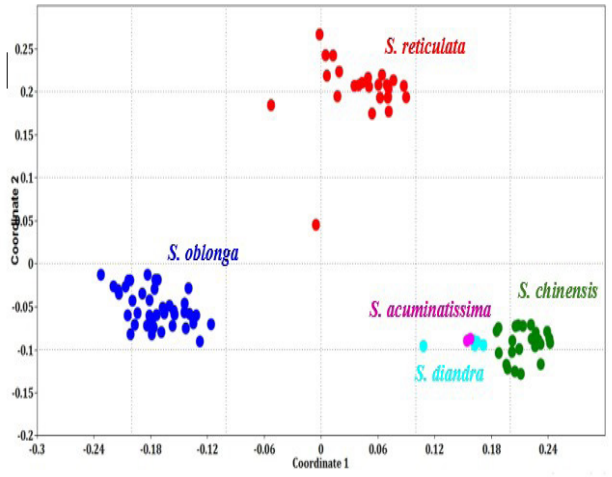


Figure 1: Score plot of principal coordinates for quantitative and qualitative variables

Geographical distribution, identification and evaluation of conservation statuses of *Salacia*:

An island-wide survey recorded 98 populations of *Salacia* across 13 districts, spanning all major climatic zones of Sri Lanka. *Salacia diandra* (including *S. acuminatissima*) was restricted to the wet zone, whereas *S. chinensis* occurred mainly in the dry zone with limited presence in the intermediate zone. *Salacia oblonga* was largely confined to the wet and intermediate zones, while *S. reticulata* was distributed across dry and intermediate zones, with occasional occurrences in the wet zone (Figure 3).

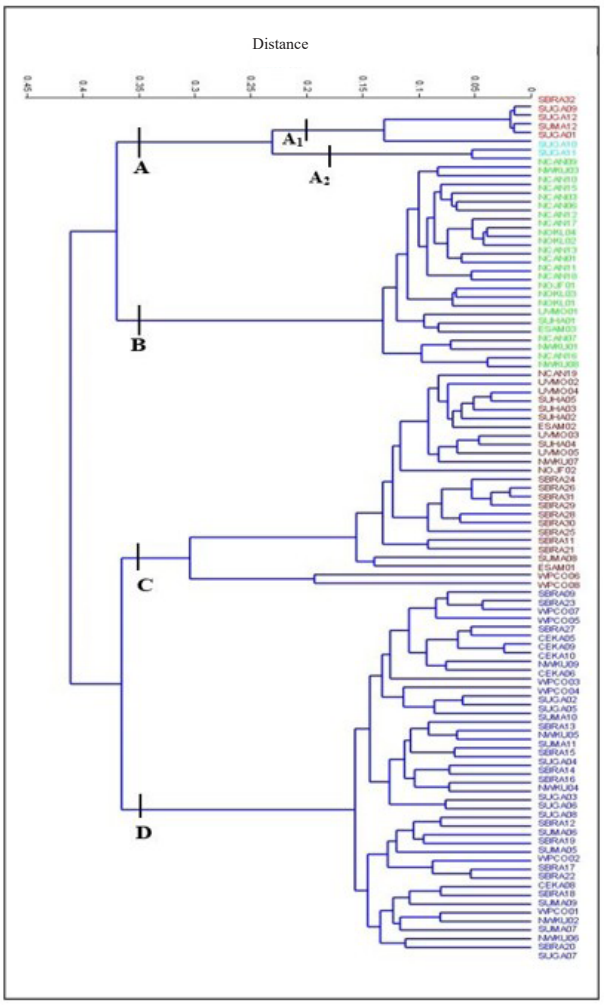


Figure 2: Phenogram depicting the groups within *Salacia* using vegetative and leaf anatomical characters (A1 – *S. diandra*, A2 – *S. acuminatissima,* B – *S. chinensis*, D – *S. reticulata*, D – *S. oblonga*)

Vegetative, reproductive, and wood anatomical traits are useful for identifying *Salacia* species despite their close similarities. *Salacia diandra* is distinguished by four-petalled flowers, dark green elliptic leaves, and yellowish-brown bark with flower-shaped concentric rings. *Salacia chinensis* has elliptic leaves with crenate margins, delicate fruits, and brownish-grey bark with wavy concentric rings. *Salacia oblonga* is characterized by oblong leaves, greenish-yellow flowers, and blackish-brown bark with lenticels, while *S. reticulata* shows elliptic to lanceolate leaves, yellowish-green flowers, and thick wavy concentric rings. Common wood anatomical features across the genus include similar vessel and parenchyma patterns, absence of growth rings, and predominance of uniseriate rays except in *S. diandra*, which has biseriate rays.

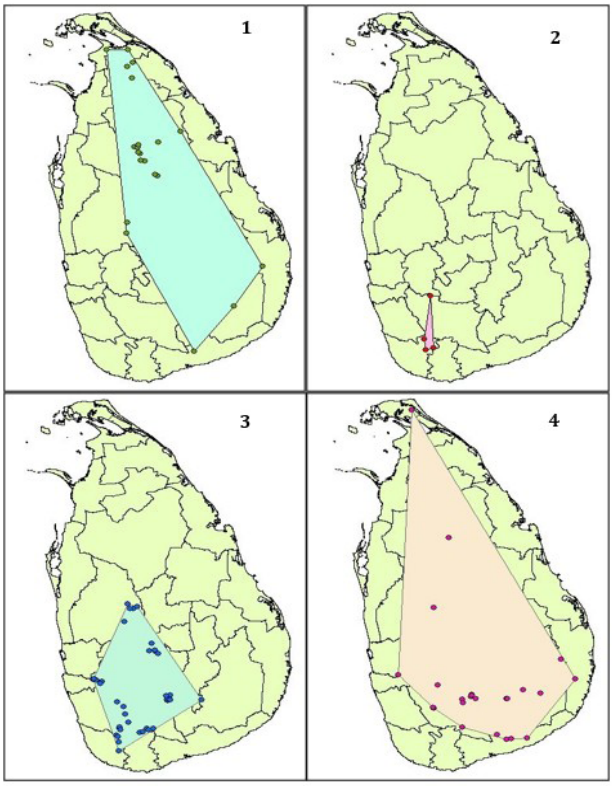


Figure 3: Sampling locations of *Salacia* species in Sri Lanka with distribution maps, generated for the evaluation of conservation statuses: 1 – *S. chinensis*, 2 – *S. diandra,* 3 – *S. oblonga*, 4 – *S. reticulata*

Preliminary chemotaxonomic analysis using TLC revealed common metabolite patterns across species, with potential genus-specific markers, though these were insufficient for species delimitation. DNA barcoding using ITS and *psb*A–*trn*H regions identified limited variation but provided the first barcode data for Sri Lankan *Salacia*.

Based on IUCN criteria, the conservation status of *S. diandra* (including *S. acuminatissima*) and *S. chinensis* remains unchanged as Endangered (EN) and Near Threatened (NT), respectively. However, *S. oblonga* and *S. reticulata* are revised from Endangered to Near Threatened due to wider distribution and numerous newly recorded localities.

Conclusion

In conclusion, four *Salacia* species are confirmed in Sri Lanka: *S. chinensis*, *S. diandra*, *S. oblonga*, and *S. reticulata*. *Salacia acuminatissima* is synonymized under *S. diandra*, consistent with previous taxonomic treatments.

Conservation statuses of *S. diandra* (syn. *S. acuminatissima*) and *S. chinensis* remain Endangered (EN) and Near Threatened (NT), respectively, while *S. oblonga* and *S. reticulata* are reassessed from Endangered to Near Threatened due to wider distributions and new localities (76% and 64%, respectively).

Morphological identification is supported by key diagnostic traits: *S. diandra* (syn. *S. acuminatissima*) is distinguished by four-petalled flowers with two stamens and caudate leaf tips; *S. chinensis* by its delicate fruit exocarp; *S. oblonga* by oblong leaves with a rounded base, lenticellate stems, and lanceolate petals; and *S. reticulata* by attenuate leaf bases and yellowish-green orbicular petals. Wood anatomy is largely conserved across the genus, with biseriate rays unique to *S. diandra* and uniseriate rays in the remaining species.

Preliminary chemotaxonomic analysis suggests potential genus-specific markers (Rf 0.90–0.91 and 0.74–0.76), though further validation is required. DNA barcoding using ITS and *psb*A–*trn*H regions revealed limited variation, reflecting close genetic relationships among species and providing baseline barcode data for Sri Lankan *Salacia*.

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INVESTIGATING SECONDARY MATHEMATICS TEACHERS' PEDAGOGICAL CONTENT KNOWLEDGE (PCK) AND ITS ROLE IN STUDENTS' ALGEBRAIC UNDERSTANDING: IMPLICATIONS FOR A PCK-BASED PROFESSIONAL DEVELOPMENT MODEL



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Mathematics plays a vital and dynamic role in the learning and teaching process, as it is both intellectually challenging and continuously evolving within modern education. It serves as a fundamental subject that equips school leavers with a wide range of knowledge, skills, attitudes, and problem-solving abilities required for successful participation in contemporary society. Therefore, the development of mathematical competence has become an essential requirement for learners to effectively navigate academic, professional, and everyday life situations in the twenty-first century. Literature describes that mathematics consists of concepts, facts, principles, and operations which are necessary to develop students' mathematics competence. Mathematics education is the foundation for the existence of every individual. Further mathematics is an essential need in manipulating and handling all human life activities. It is standardized that mathematics education is deeply connected with communication, planning, designing, and problem-solving in daily life. Literature further mentions that the mathematics competencies must be compulsorily achieved by each and every student Mathematics is essential for developing the students' creativity in the 21st century.

Mathematics is a very complex subject area that consists of many components, and algebra is identified as the most changeable component in mathematics teaching and learning process. However, many issues and challenges are faced by the learners and the teachers as well. The factor that related to the subject matter knowledge of facts and concepts in mathematics is not the only factor in this regard and developing mathematical competence has become a severe problem in the education system of Sri Lanka. Similarly, research findings suggest that teacher related factors affect the students' understanding strongly. Further investigations on teacher related factors reveal that deficiencies in teachers' Pedagogical Content Knowledge (PCK) negatively affect the students' precise understanding. Hence, mathematics teacher competencies in organizing, planning and implementing creative mathematics lessons have been identified as very important. Further, the teachers should possess different innovative techniques to impart knowledge skills and attitudes among students to enhance the students' mathematics competencies. In this regard, PCK in teacher knowledge is identified as the major influencing factor of productivity in mathematics education. Moreover, PCK is not a static attribute; rather, it is a dynamic and evolving process that involves teachers' self-assessment, reflection, and continuous professional growth. However, the professional development of mathematics teachers, particularly in the teaching of algebra, remains

inadequate, which directly affects students' conceptual understanding. Previous studies have highlighted concerns regarding both the effectiveness and quality of existing professional development (PD) programmes related to PCK. Scholars have emphasized that many PD programmes implemented in the past lacked sufficient focus on content knowledge and effective pedagogical practices. Therefore, there is a pressing need for a well-designed professional development model to enhance mathematics teachers' PCK in teaching algebra within the Sri Lankan educational context. This research aimed to investigate and develop mathematics teachers' PCK in algebra by introducing a PD model.

Methodology

This research was conducted in two phases. The first phase examined the current level of mathematics teachers' PCK competencies quantitatively and qualitatively, while the second phase introduced a PD model to enhance teachers' PCK. Teachers' PCK in algebra was investigated focusing on the concepts of symbols and variables at the initial stage of students' algebra learning. Two standardized questionnaires were used to assess mathematics teachers' PCK, and eight mathematics teachers were observed across 24 algebra lessons. In the second phase, a well-designed PD model was implemented through a series of one-day workshops conducted Island wide (Figure 1).



Figure 1: A workshop on professional development for teachers

Both quantitative and qualitative data were analyzed using SPSS (Version 26), SPSS AMOS (Version 25), and thematic analysis. All workshops were conducted focusing on conceptual understanding through internationally recognized teaching techniques supported by relevant visuals and learning aids.

Results and Discussion

The key findings of the study revealed that mathematics teachers' PCK in teaching algebra was at a moderate level, with similar results found for teaching algebraic symbols and variables. Since sixth-grade students are at a critical stage of learning abstract algebraic concepts, the development of mathematics teachers' PCK in sixth-grade algebra was identified as essential.

The findings further showed that teachers' PCK in teaching even basic algebraic concepts, such as symbols and variables, was limited and below a satisfactory level. Therefore, the results of the first phase emphasized the need for a PD program to enhance mathematics teachers' PCK.

In the second phase, mathematics teachers from all nine provinces of Sri Lanka confirmed the first-phase findings regarding the lack of competencies in teaching algebra at the acquisition stage. The participants of the PD workshops demonstrated the effectiveness of the designed model, which improved both their teaching methodologies and their awareness of effective approaches to teaching algebra.

Conclusion

The study found that both the strengths and limitations of mathematics teachers' PCK influenced students' understanding of basic algebra at the acquisition stage. The findings revealed that teachers' PCK in teaching algebraic symbols and variables was limited. In particular, teachers showed insufficient awareness in guiding students through the critical transition from concrete concepts to abstract algebraic thinking. Furthermore, teachers demonstrated limited attention to developing students' problem-solving abilities and algebraic thinking skills, which are essential for learning abstract algebra effectively.

The results also indicated that sixth-grade students had limited achievement in basic algebraic concepts. However, the designed PD model, which focused on developing algebraic thinking, proved effective in enhancing teachers' PCK. The study therefore suggests that both pre-service and in-service mathematics teacher training programs should be revised to include effective strategies and approaches for teaching abstract algebra.

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THE EFFECT OF PRE-SERVICE TEACHER DEVELOPMENT PROCESS ON THE USE OF CONSTRUCTIVIST APPROACH TO TEACH MATHEMATICS IN SECONDARY CLASSES



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In recent decades, educational reforms across the world have increasingly emphasized learner-centered teaching approaches that encourage students to actively construct knowledge through inquiry, collaboration, and reflection. Among these approaches, constructivism has emerged as a widely accepted framework for promoting meaningful learning and developing higher-order thinking skills. In Sri Lanka, constructivist principles form a central component of teacher education programs offered through the National Colleges of Education, which are responsible for preparing future teachers for the national school system.

The mathematics curriculum in Sri Lankan secondary schools advocates active learning, problem-solving, and student engagement. Consequently, prospective mathematics teachers are expected to apply constructivist teaching strategies that facilitate exploration, discussion, and critical thinking rather than relying solely on traditional teacher-centered instruction.

Despite these expectations, many new teachers face challenges in translating their theoretical understanding of constructivism into effective classroom practice. Recognizing this challenge, the present study examined how pre-service teacher development influences the implementation of constructivist approaches in secondary school mathematics classrooms. The research aimed to identify the factors that support or hinder constructivist teaching among prospective mathematics teachers and to explore whether targeted professional development could strengthen the application of constructivist principles during teaching practice.

Methodology

This study employed an explanatory sequential mixed methods design to gain a comprehensive understanding of how pre-service teacher development influences the implementation of constructivist approaches in secondary school mathematics teaching. The study was conducted in three interconnected phases, combining quantitative and qualitative evidence with a professional development intervention to provide a comprehensive understanding of the issue.

The first phase involved a quantitative investigation with 160 prospective mathematics teachers enrolled in two National Colleges of Education in Sri Lanka. Data were collected using a structured questionnaire designed to assess participants' knowledge of constructivist learning theories, attitudes toward constructivist teaching, self-perceived readiness to implement constructivist practices, and perceptions of support received from lecturers and teacher educators. Statistical analysis of

the survey data was undertaken to identify patterns and relationships among these variables and to provide an overall picture of prospective teachers' preparedness for constructivist teaching.

Building on the quantitative findings, the second phase explored participants' experiences in greater depth through qualitative methods. Twenty prospective mathematics teachers and five teacher educators participated in semi-structured interviews, while classroom observations, lesson plans, and reflective journals provided additional sources of evidence. These multiple data sources enabled a detailed examination of the opportunities, challenges, and contextual factors that influenced the implementation of constructivist strategies during teaching practice. The qualitative phase offered valuable insights into the realities of classroom teaching and helped explain the gaps identified in the quantitative data.

Drawing on findings from the first two phases, the final stage of the study involved the design and implementation of a ten-day professional development workshop. The workshop aimed to strengthen prospective teachers' capacity to apply constructivist principles in mathematics classrooms by bridging the gap between theory and practice. Participants engaged in collaborative lesson planning, micro-teaching activities, peer discussions, guided reflection, and practical demonstrations of constructivist instructional strategies. These activities provided opportunities to rehearse, refine, and critically evaluate teaching practices within a supportive learning environment. The intervention also served as a platform for examining how targeted professional development could enhance the classroom application of constructivist pedagogy among future mathematics teachers.

Results and Discussion

The findings of the study revealed a noteworthy contrast between prospective mathematics teachers' theoretical understanding of constructivist pedagogy and their actual classroom practices. Quantitative data showed that 95% of participants demonstrated a sound awareness of constructivist principles, while 98% expressed positive attitudes toward the use of student-centered approaches in mathematics teaching. These results suggest that the teacher education programs offered by the National Colleges of Education have been successful in fostering an understanding of constructivist concepts and developing favorable beliefs about learner-centered instruction.

Regardless of this strong theoretical foundation, classroom observations and qualitative evidence indicated that many prospective teachers experienced difficulties when attempting to apply constructivist principles in real teaching situations. Traditional teacher-centered methods continued to dominate a considerable number of lessons, revealing a persistent gap between what prospective teachers knew and what they were able to implement in practice. This discrepancy highlights one of the central challenges in teacher education: transforming pedagogical knowledge into effective classroom action.

Insights gathered through interviews, lesson plan analyses, reflective journals, and classroom observations helped explain the factors contributing to this theory–practice gap. Many participants reported that although constructivist approaches were extensively discussed during coursework, they were not consistently modeled by lecturers. As a result, prospective teachers often lacked concrete examples of how these principles could be translated into meaningful classroom activities. Participants also identified limitations in the mentoring and feedback they received during teaching practice. Feedback tended to focus on lesson completion, content coverage, and classroom management rather than on promoting student engagement, inquiry, and knowledge construction. Furthermore, a weak alignment between coursework and practicum experiences often discouraged the implementation of innovative teaching methods. In many school settings, prospective teachers encountered established practices that favored traditional instruction, making it difficult to experiment with learner-centered approaches.

To address these challenges, a ten-day professional development workshop was implemented as the final phase of the study. The workshop provided opportunities for collaborative lesson planning, micro-teaching, guided reflection, and practical demonstrations of constructivist teaching strategies. The impact of this intervention was clearly evident in subsequent classroom observations. Before the workshop, only 30% of observed lessons demonstrated effective scaffolding of learning, while teacher facilitation was evident in just 35% of lessons. Following the intervention, scaffolding increased to 80%, and teacher facilitation was observed in all lessons. Similarly, active student participation, which had previously been limited, became a prominent feature of classroom instruction, while formative assessment practices shifted from being rarely observed to being regularly integrated into lessons.

The professional development experience enabled participants to move beyond a theoretical appreciation of constructivism and engage directly with its practical application. Through rehearsal, collaboration, and reflection, prospective teachers gained greater confidence in designing learning environments that encouraged inquiry, discussion, and active student engagement. An additional outcome of the intervention was the noticeable improvement in reflective practice. Analysis of reflective journals showed that participants developed a deeper capacity to evaluate and refine their teaching. Fourteen participants demonstrated analytical reflection, while six achieved critical reflections by questioning

assumptions, considering contextual influences, and identifying opportunities for professional growth.

Taken together, the findings emphasize that knowledge of constructivist pedagogy alone is insufficient to ensure its successful implementation. Effective teacher preparation requires opportunities for prospective teachers to observe, practice, and reflect upon constructivist teaching in authentic settings. The study reinforces the importance of integrating explicit modeling, structured mentoring, collaborative lesson design, constructive feedback, and continuous reflection within teacher education programs. Such experiences can play a crucial role in helping future mathematics teachers bridge the gap between theory and practice and develop the confidence and competence needed to create meaningful, student-centered learning experiences.

Conclusion

This study investigated the influence of pre-service teacher development on the implementation of constructivist approaches in secondary school mathematics teaching within Sri Lanka's National Colleges of Education. While prospective mathematics teachers demonstrated strong theoretical understanding and positive attitudes toward constructivism, substantial challenges remained in translating this knowledge into classroom practice.

The findings revealed that inadequate modeling, limited mentoring, and weak connections between coursework and practicum experiences contributed significantly to the theory–practice gap. However, the professional development intervention demonstrated that targeted support can effectively enhance teachers' ability to implement constructivist strategies.

Improvements in scaffolding, facilitation of learning, formative assessment, student participation, and reflective practice illustrate the transformative potential of well-designed professional development experiences. The study underscores the importance of embedding modeling, collaborative lesson design, guided practice, feedback, and reflective cycles within pre-service teacher education programs.

As Sri Lanka continues to promote learner-centered education, strengthening the practical dimensions of teacher preparation remains essential for developing effective and reflective mathematics teachers. By bridging the gap between theory and classroom practice, National Colleges of Education can prepare future mathematics teachers who are confident, reflective, and capable of creating engaging, inquiry-based learning environments that support meaningful student learning.

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DEVELOPMENT OF PREDICTIVE MODELS TO IDENTIFY THE RISK OF METABOLIC SYNDROME IN URBAN AND SEMI URBAN AREAS IN COLOMBO DISTRICT, SRI LANKA



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Metabolic Syndrome (MetS) is a cluster of interrelated risk factors including central obesity, raised triglycerides, reduced HDL cholesterol, elevated blood pressure, and impaired fasting glucose that collectively increase the risk of cardiovascular disease, type 2 diabetes, and stroke. Defined by the International Diabetes Federation (IDF, 2006), MetS is diagnosed when an individual present with central obesity plus any two additional criteria from the above factors. Globally, its prevalence is estimated at 20–25% and continues to rise, placing a significant burden on healthcare systems worldwide. In Sri Lanka, the rising trend of MetS is particularly concerning in urban and semi-urban areas driven by rapid lifestyle changes, sedentary behavior, dietary shifts, and increasing urbanization. National studies reported a prevalence of 27.1% among adults, with rates exceeding 30% in metropolitan areas such as Colombo. A key methodological gap exists in the literature: most predictive models for MetS have been developed in non-South Asian populations and applied without local calibration. Furthermore, conventional statistical approaches often fail to account for complex, non-linear interactions among risk factors. This study addresses this gap by developing and evaluating predictive classification models for MetS using Sri Lankan population data from the Colombo District, explicitly accounting for risk factor interactions and urban, semi-urban differences. The main objective of the study is to identify the clinically significant finding is that accurate MetS prediction is achievable without any blood tests or the metabolic laboratory parameters used to define MetS enabling low-cost, community-level early screening through a simple questionnaire alone and to identify the most important features that predict the occurrence of MetS.

Methodology

This study used a secondary dataset from the “Asian American Centers for Arbovirus Research and Surveillance” community study conducted in the Colombo district from March to August 2022. The study concurrently collected comprehensive metabolic data, making it fully valid for MetS prediction. A total of 1,294 permanent residents aged 17–80 years were recruited: 689 from the urban area (Kirulapana) and 605 from the semi-urban area (Boralesgamuwa). Pregnant women, temporary residents, severely ill, and bed-ridden individuals were excluded. Ethical clearance was obtained from the Ethics Review Committee of the University of Sri Jayewardenepura. Data collection covered socio-demographic variables (gender, age group, occupation, area of living), laboratory parameters (fasting blood glucose, total cholesterol, triglycerides, HDL and LDL cholesterol), and anthropometric and blood pressure measurements (BMI, waist circumference, systolic and diastolic blood pressure). Metabolic syndrome was labelled as the binary response variable (present/absent) according to IDF criteria. Eight derived categorical variables were created (e.g., diabetes status, hypertension status, BMI category, waist status) to improve interpretability. Missing data primarily arose from participants who did not attend the bleeding session.

Preliminary analysis included normality testing (Shapiro-Wilk and Kolmogorov-Smirnov), outlier detection via the Interquartile Range (IQR) method, Pearson correlation for continuous variables, Chi-Square tests (with post hoc standardized residuals and Bonferroni correction) for categorical associations, two-sample t-tests, and one-way ANOVA. Six predictive models were developed and compared: (1) Binary Logistic Regression, (2) Binary Logistic Regression with LASSO regularization (L1 penalty for automatic feature selection), (3) Decision Tree (Gini impurity criterion with post-pruning), (4) Random Forest (bootstrap sampling with hyperparameter tuning), (5) XGBoost (sequential gradient-boosted trees with L1/L2 regularization), and (6) Neural Network (two hidden layers). Model evaluation employed k-fold cross-validation, with performance assessed using accuracy, sensitivity, specificity, F1 score, AUC-ROC, and confusion matrices. Grid Search CV was used to optimise hyperparameters for XGBoost.

Results and Discussion

The study sample comprised 61.28% females and 38.72% males, with a mean age of approximately 49 years. Half the participants were unemployed (50.39%), and 53.25% resided in the urban area. The overall prevalence of MetS in Colombo was strikingly high at 55.87%, far exceeding the national average of 27.1% reported in 2019. MetS prevalence was significantly higher in the urban area (48.33%, n=333/689) compared to the semi-urban area (39.11%, n=238/606) (p=0.001). The highest MetS prevalence (73.11%) was found among females aged 51–60 years in urban areas, reflecting the combined effect of hormonal changes and urban lifestyle risk factors. Diabetes prevalence was highest among females aged 61–70 years (73.9%). Among urban slum females, 43.8% were obese (BMI >30) and 66.43% had central obesity.

Among all six models, Binary Logistic Regression with LASSO achieved the best overall performance: 81% accuracy (95% CI: 0.76–0.85), sensitivity of 0.76, specificity of 0.86, and the highest AUC of 0.92. Standard Logistic Regression achieved 70% accuracy with high specificity (0.88) but limited sensitivity (0.50). The Neural Network achieved 68% accuracy with an AUC of 0.74. The Decision Tree attained 65% accuracy with the highest sensitivity (0.75) among the non-LASSO models but lower specificity (0.56). XGBoost achieved 64.8% accuracy (AUC = 0.68), while Random Forest yielded 68% accuracy (AUC = 0.67) with strong specificity (0.82). Tree-based and neural network models showed only moderate accuracy, likely reflecting the challenges of small-to-moderate dataset sizes, class heterogeneity, and potential overfitting in complex non-linear architectures.

Across models, gender, age, BMI, and triglycerides were consistently the most important predictors of MetS. The LASSO Logistic Regression model built using only socio-demographic variables and medical history, with zero blood tests or metabolic laboratory parameters achieved 81% accuracy and an AUC of 0.92. This outperformed every model that did include blood test and clinical data. This demonstrates conclusively that MetS risk can be accurately identified in a community screening context without any clinical investigation. XGBoost further highlighted gender, age categories (51–60 years), systolic blood pressure, total cholesterol, and central obesity (waist circumference) via SHAP analysis. Random Forest identified gender, BMI, LDL, central obesity, and total cholesterol as highly important. The Decision Tree indicated gender, previous hypertension status, triglycerides, and diastolic blood pressure as the most discriminating variables. Neural Network analysis pointed to older age groups (61–80 years), male gender, and employment-related socioeconomic factors. These findings align closely with comparable studies from other South Asian contexts while confirming the primacy of modifiable lifestyle and metabolic factors in the Sri Lankan setting.

The exceptionally high prevalence of MetS (55.87%) observed in this study substantially above LASSO logistic regression over more complex models is consistent with the broader biomedical machine learning literature, where regularized linear models tend to outperform complex algorithms on small-to-moderate clinical datasets. These findings emphasize that careful feature selection and regularization often yield more clinically interpretable and generalizable models than increasing algorithmic complexity. The study also highlights urban residence, advancing age, female gender, and elevated BMI as actionable targets for early intervention and public health policy in Sri Lanka.

Conclusion

This study demonstrates that LASSO logistic regression offers a robust, interpretable, and clinically relevant tool for predicting MetS in the Sri Lankan urban context without laboratory tests. Tree based models identified prominent features important in predicting MetS, such as gender, age, BMI, and triglycerides, which are the primary modifiable and non-modifiable risk factors across all models. Future research should focus on longitudinal studies, dietary and genetic data, and the practical clinical implementation of these predictive models to enhance early detection and prevention of metabolic syndrome in Sri Lanka.

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GREEN TEMPLATE-SEGMENTATION OF DIABETIC RETINOPATHY LESIONS AND CLASSIFICATION OF DIABETIC RETINOPATHY USING ULTRA WIDE OCT ANGIOGRAPHY IMAGING AND DEEP LEARNING



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Diabetic Retinopathy (DR) is one of the leading causes of vision impairment and blindness worldwide, particularly among individuals living with long-term diabetes. As the global diabetic population continues to rise, early detection and accurate monitoring of DR have become increasingly important to prevent irreversible vision loss. DR damages the tiny blood vessels in the retina, leading to abnormalities such as hemorrhages, non-perfusion regions, and abnormal blood vessel growth. If left untreated, these pathological changes can gradually progress to severe visual impairment or complete blindness.

Traditionally, ophthalmologists rely on manual interpretation of retinal imaging modalities such as fundus photography, fluorescein angiography, and Optical Coherence Tomography (OCT) to identify DR-related abnormalities. However, manual assessment is time-consuming, subjective, and highly dependent on clinical expertise. In recent years, Ultra-Wide Optical Coherence Tomography Angiography (UW-OCTA) has emerged as a promising imaging modality because it provides detailed visualization of retinal blood flow and vascular abnormalities without requiring invasive dye injections. Furthermore, UW-OCTA captures a wider retinal field than conventional OCTA, enabling improved identification of peripheral retinal lesions that may otherwise remain undetected.

Despite these advantages, analyzing UW-OCTA images remains challenging due to image artifacts, variable image quality, subtle lesion appearance, and the complexity of retinal vascular structures. These limitations motivate the need for automated intelligent systems capable of assisting clinicians in accurate DR diagnosis and disease monitoring. This research focused on developing deep learning-based approaches for three important tasks in diabetic retinopathy analysis using UW-OCTA imaging:

1. Image Quality Assessment (IQA)
2. Lesion Segmentation
3. Disease Severity Classification

Together, these tasks contribute toward building a comprehensive automated framework for diabetic retinopathy screening and clinical decision support.

Methodology

The study utilized publicly available UW-OCTA datasets from the DRAC2022 challenge. The datasets included retinal images with annotations related to each task. Since the dataset size is limited and imbalanced, extensive preprocessing and augmentation techniques were employed to improve model robustness and generalization.

1. Image Quality Assessment

Image quality plays a crucial role in reliable disease diagnosis because poor-quality scans can significantly

affect lesion detection and disease grading performance. A total of 665 UW-OCTA images categorized as poor, good, and excellent quality were used. Since the dataset was highly imbalanced, selective augmentation techniques such as brightness adjustment, Gaussian blur, noise injection, and flipping were applied to the underrepresented classes.

For automated quality assessment, a deep learning model based on DenseNet121 integrated with a Convolutional Block Attention Module (CBAM) was developed. The proposed architecture was designed not only to classify image quality into discrete categories but also to generate a continuous quality score ranging from 0 to 100, enabling more flexible assessment of borderline cases.

2. Lesion Segmentation

The second component of the research focused on automated segmentation of three clinically significant DR lesions: Intraretinal Microvascular Abnormalities (IRMA) , Non-Perfusion Areas (NPA), Neovascularization (NV) . Even though the segmentation is difficult due to the subtle appearances of vascular abnormalities it is critical because lesions directly reflect the disease progression.

To address these challenges, an enhanced Attention U-Net architecture with attention gates and skip-connection attention mechanisms was implemented. Separate models were trained for each lesion type using lesion-specific composite loss functions combining Dice Loss, Tversky Loss, and Focal Loss. Careful augmentation techniques were applied while preserving clinically meaningful vascular structures.

3. DR Severity Classification

The final task involved classifying UW-OCTA images into three categories: Normal (Non-DR) ,Non-Proliferative Diabetic Retinopathy (NPDR) and Proliferative Diabetic Retinopathy (PDR) .A CBAM-enhanced DenseNet121 architecture was again utilized for severity grading. Data augmentation strategies such as rotations, flipping, gamma correction, and brightness adjustment were selectively applied to improve model performance on underrepresented classes.

Results and Discussions

For image quality assessment, the DenseNet121-CBAM model achieved an overall classification accuracy of 97.01% (Table 1). The model successfully differentiated poor, good, and excellent quality scans while also generating a continuous quality score for each image. The integration of the CBAM attention mechanism significantly improved the model's ability to focus on important retinal regions affected by noise, blur, and motion artifacts. The continuous scoring approach provided additional flexibility in identifying borderline-quality images, which may be beneficial in practical clinical environments (Figure 1).

Table 1. Performance comparison of models on the UW OCTA image quality assessment task

Model	Accuracy	QWK	AUC
Vgg16	68%	0.8025	0.8312
CNN	68.62%	0.7730	0.7872
DenseNet169	86.62%	0.9032	0.9338
ResNet50	88.10%	0.8895	0.9729
DenseNet121	94.23%	0.9512	0.9778
CBAM+DenseNet121	97.01%	0.9787	0.9959

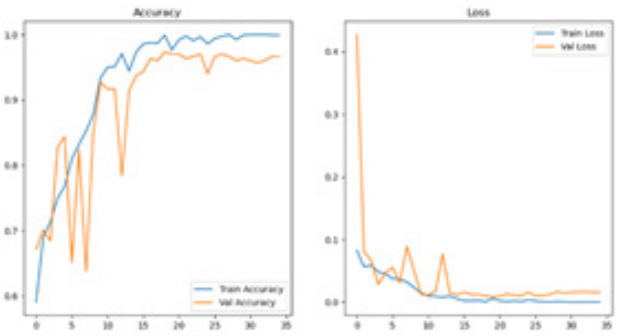


Figure 1: Accuracy and Loss graphs of Image Quality assessment task

In the lesion segmentation task, the proposed Attention U-Net-based framework achieved strong segmentation performance for all three lesion types. The Dice scores obtained were 0.5700 for IRMA, 0.8337 for NPA, and 0.8035 for NV lesions (Table 2). The results indicate that the model was highly effective in detecting larger and more distinguishable vascular abnormalities such as NPA and NV. Although IRMA segmentation remained comparatively challenging due to the subtle and complex appearance of these lesions, the proposed model still demonstrated improved performance compared to several previously reported approaches. The use of attention mechanisms and lesion-specific composite loss functions contributed significantly to improving segmentation accuracy and reducing false detections.

Table 2. Performance comparison of models on the UW OCTA image segmentation task

Model	Lesion	Dice	IoU
U-Net	IRMA	0.3037	0.2546
Attention U-Net		0.4996	0.3330
Attention U-Net with attention		0.5700	0.4311
U-Net	NV	0.4835	0.3188
Attention U-Net		0.3372	0.2987
Attention U-Net with attention		0.8035	0.6808
U-Net	NPA	0.6600	0.4920
Attention U-Net		0.7237	0.5975
Attention U-Net with attention		0.8337	0.7478

For diabetic retinopathy severity grading, the proposed classification framework achieved an overall accuracy of 87.78% in distinguishing Normal, NPDR, and PDR stages (Table 3). The model effectively captured vascular patterns and disease-related retinal abnormalities from UW-OCTA images (Figure 2). The attention-enhanced architecture improved feature extraction capability and enabled better discrimination between intermediate disease stages, particularly between NPDR and PDR.

Table 3. Performance comparison of DR severity grading models

Model	Accuracy	QWK	AUC
EfficientNetB0	77.66	0.8015	0.9176
DenseNet169	78.68	0.8283	0.9189
ResNet50	80.79	0.8279	0.8829
VGG16	83.32	0.8089	0.9012
DenseNet121	86.02	0.8820	0.9538
CBAM + DenseNet121	87.78	0.9002	0.9670

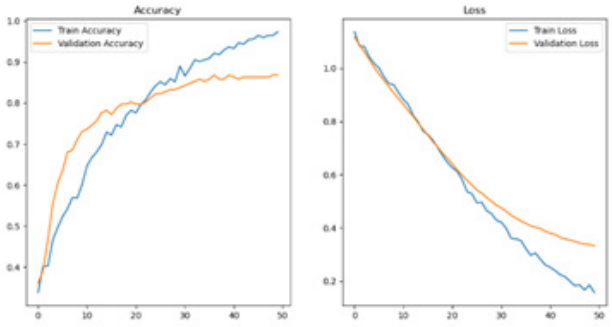


Figure 2: Accuracy and Loss curves for DR severity grading task

Overall, the findings demonstrate that deep learning approaches can effectively support automated diabetic retinopathy analysis using UW-OCTA imaging. The integration of image quality assessment, lesion segmentation, and disease grading contributes toward the development of reliable AI-assisted diagnostic systems for ophthalmology. Furthermore, this research highlights the importance of attention mechanisms, task-specific optimization strategies, and quality-aware analysis in improving medical image interpretation.

Conclusion

This research presented deep learning-based methods for automated diabetic retinopathy analysis using Ultra-Wide Optical Coherence Tomography Angiography imaging. The study addressed three important tasks: image quality assessment, lesion segmentation, and disease severity grading. The proposed DenseNet121-CBAM framework achieved high accuracy in image quality classification while introducing a continuous quality scoring mechanism for improved interpretability. The enhanced Attention U-Net models demonstrated strong capability in segmenting clinically significant retinal lesions including IRMA, NPA, and NV. In addition, the severity grading framework successfully classified retinal images into Normal, NPDR, and PDR categories with promising accuracy.

The findings of this research demonstrate the potential of artificial intelligence and deep learning techniques in supporting ophthalmologists through automated and reliable diabetic retinopathy analysis. The proposed approaches can contribute toward reducing clinical workload, improving diagnostic consistency, and supporting early disease detection, particularly in resource-limited healthcare environments.

Future work can focus on integrating all three tasks into a unified multi-task learning framework capable of simultaneously performing three tasks within a single end-to-end diagnostic pipeline.

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DEEP LEARNING-BASED DETECTION OF MITOTIC CELLS IN MICROSCOPIC HISTOPATHOLOGY IMAGES



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Cancer is a major health concern worldwide. Among the various types of cancer, breast cancer is the most prevalent. Breast cancer is a disease in which abnormal cells in the breast grow uncontrollably and form a tumor. Over time, these cells can invade nearby tissues or spread to other parts of the body. According to global cancer statistics published in 2018, breast cancer is the leading cause of cancer-related mortality among women, accounting for approximately 15% of all female cancer deaths. Furthermore, it accounts for about 24.2% of all newly diagnosed cancer cases in women. Accurate prognosis and treatment planning for breast cancer rely heavily on histopathological markers, particularly the mitotic count.

Mitosis refers to the process in which a eukaryotic cell divides its nucleus and cytoplasm, resulting in two genetically identical daughter cells. It occurs in several stages: prophase, metaphase, anaphase, and telophase, followed by cytokinesis. Each stage is characterized by distinct morphological features that can be observed under the microscope, including chromatin condensation, breakdown of the nuclear membrane, alignment of chromosomes at the metaphase plate, separation of chromatids, and reformation of the nuclear envelope. Mitosis is essential for growth, development, and tissue repair. However, in pathology, particularly cancer, uncontrolled mitotic activity often indicates high malignancy. Thus, mitosis is a crucial stage in the cell cycle.

The study of mitosis can provide valuable insights into how cells behave in culture. The treatment strategy for breast cancer depends on the disease grade and expected prognosis, and early detection is crucial for reducing mortality rates. Mitotic count is a key parameter in cancer diagnosis within oncology, as it helps evaluate how rapidly a tumor is proliferating. Generally, a higher mitotic rate is associated with more aggressive cancers and a poorer patient prognosis.

In the context of cancer, the rate of mitosis is a direct indicator of cell proliferation, which is often dysregulated in malignant tumors. The role of mitosis detection in cancer diagnosis and grading is important, as the frequency of mitotic figures within a tissue sample can reveal the biological behavior of a tumor.

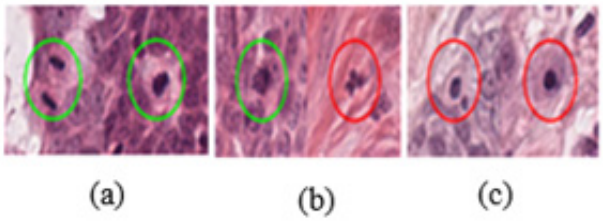


Figure 1: (a) Mitotic (b) Non-Mitotic (c) Difference between mitotic and non-mitotic

Pathologists typically carry out manual mitotic detection by inspecting tissue sections under a microscope, identifying cells at various mitotic stages, and counting the number of mitotic figures within a specific region. Manual detection of mitotic figures poses several

challenges: it is subjective, time-consuming, and requires extensive scanning of large tissue samples, making it labor-intensive and prone to errors. Accurately distinguishing mitotic figures from similar structures, such as apoptotic bodies or cells with abnormal nuclei, further complicates the process. In addition, variations in tissue preparation, staining, and observer expertise can lead to inconsistent counting results. Manual detection of mitotic figures depends strongly on the pathologist's expertise and subjective judgment, as it requires visual identification under a microscope (Figure 1).

This can result in inter-observer variability, where different pathologists report different counts for the same sample, as well as intra-observer variability, where the same pathologist may produce different counts at different times. Such inconsistencies can affect cancer grading and, consequently, influence treatment decisions. Therefore, an automated system is needed to address these issues. Due to the limitations of manual counting, traditional machine learning methods were introduced. However, traditional image processing approaches face several issues due to their heavy reliance on handcrafted features such as texture, color, and shape to identify mitotic figures. These features are often designed for specific datasets, leading to poor generalization. As a result, such methods tend to perform poorly when applied to images from different sources or with variations in staining and image quality. Additionally, their accuracy is limited, as they frequently produce a high number of false positives and false negatives.

As a result of the limitations of traditional machine learning techniques in mitotic counting, deep learning-based methods were introduced. Deep learning-based object detection has become a highly effective approach across a wide range of domains, including the analysis of microscopic histopathology images. Histopathological images exhibit substantial variability arising from differences in tissue preparation, staining procedures, including variations in intensity and uniformity, imaging conditions, and tumor heterogeneity. These factors introduce noise and inconsistencies; however, deep learning models are capable of handling such variability, thereby enhancing robustness and improving the accuracy of mitotic cell detection.

Nevertheless, existing deep learning-based detection methods still require further improvement in terms of accuracy and robustness. Major challenges include the high variability of histopathological images and the need for extensive computational resources. These variations make it difficult for models to generalize effectively across different datasets, while some deep learning models require significant computational resources, making them impractical for real-time clinical use. To address these challenges, there is a need for advanced deep learning architectures, improved data augmentation techniques, and domain adaptation methods. Therefore, this study aims to improve the detection of mitotic figures in histopathological images in order to address the identified challenges. Various researchers have applied traditional machine learning, deep learning, and hybrid approaches to detect mitosis. Mitosis detection models trained on existing datasets often struggle to generalize effectively to new, unseen data.

While numerous deep learning approaches aim to enhance detection accuracy, they frequently neglect computational efficiency. To overcome these limitations, this study proposes a YOLOv8-based model that dynamically integrates SE and SA modules across the backbone, neck, and head, enabling adaptive feature recalibration at multiple levels of representation. The proposed framework is designed to improve detection accuracy, enhance generalization capability, reduce computational complexity, and provide more interpretable outcomes suitable for clinical use.

Methodology

This study used the Roboflow v2 mitotic dataset, which contains 304 labeled images with mitotic figures annotated at the pixel level by a pathologist. This dataset was divided into training, validation, and testing sets in a 70%, 20%, and 10% ratio, respectively.



Figure 2: Overview of the Proposed Approach

After that, four pretrained deep learning models were applied to this dataset to compare their performance: YOLOv5, YOLOv8, YOLOv11, and Faster R-CNN. Among the four models, YOLOv8 demonstrated the best performance. YOLO (You Only Look Once) is an advanced deep learning-based approach designed for

real-time object detection in computer vision. In contrast to conventional methods that process images in multiple stages, YOLO evaluates the entire image in a single forward pass, predicting bounding boxes and class probabilities simultaneously. This integrated framework enhances computational efficiency and enables faster detection while maintaining high accuracy (Figure 2).

Over time, multiple versions, including YOLOv5, YOLOv8, and YOLOv11, have been introduced with improvements in performance, speed, and architectural design. Owing to its capability to detect multiple objects rapidly and accurately, YOLO has been widely adopted in medical image analysis. In this study, as YOLOv8 achieved the best results, it was further enhanced by incorporating Squeeze-and-Excitation (SE) blocks combined with Spatial Attention (SA) mechanisms. These were adaptively applied across different stages of the network, including the backbone, neck, and head, without statically modifying the YOLOv8 architecture, in order to improve accuracy.

Results and Discussion

The models were systematically evaluated by comparing their performance based on detection accuracy. The proposed model performed better than the other selected existing models. To assess the performance of the mitosis detection model, several standard evaluation metrics were utilized. These metrics provide a comprehensive evaluation of the model's accuracy in detecting mitotic cells while reducing false positives and false negatives. Sample predictions of mitosis detection using the proposed YOLOv8n model are illustrated in Figure 3, showcasing the outputs generated by the model. These sample images help visualize the model's predictions and validate the effectiveness of the proposed methodology.

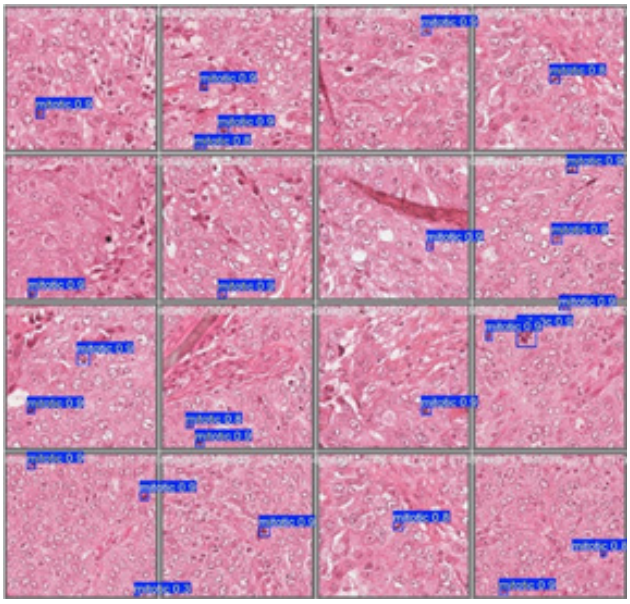


Figure 3: Sample Predictions of the Proposed YOLO Model

Conclusion

This study focused on detecting mitotic cells using object detection models on the Roboflow v2 mitotic dataset. The objective of this study is to improve the effectiveness and accuracy of cancer diagnosis using advanced technologies while minimizing false positives. Based on the obtained results, the proposed model demonstrates exceptional performance in mitotic figure detection.

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UNDERWATER IMAGE ENHANCEMENT USING DEPTH ESTIMATION AND A TRANSFORMER-GAN MODEL



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Underwater imaging is important for diverse applications including the research of ocean resources, marine ecology, rescue operations, and monitoring of deep-sea installations. Underwater images have distinct characteristics influenced by the properties of water and the unique conditions of the underwater environment. These characteristics can present challenges in capturing clear and accurate visuals. As shown in Figure 1, underwater images are often diminished due to light absorption, scattering, noise, and uneven illumination. These issues result in colour distortion, reduced sharpness, and loss of detail, highlighting the need for effective underwater image enhancement (UIE) techniques. Although recent deep learning-based approaches have demonstrated remarkable performance, their effectiveness in UIE remains limited as they often neglect valuable depth information.

This study addresses these limitations by incorporating depth information into UIE through a deep learning framework. First, a depth map is estimated from an underwater image using a CNN–Transformer-based model. The estimated depth map is then combined with the corresponding raw underwater image to provide depth information as an additional cue for enhancement. Subsequently, the fused raw image and depth map are fed into a Generative Adversarial Network (GAN) to produce visually realistic enhanced underwater images. The proposed framework is trained and evaluated using publicly available benchmark datasets. Experimental results, both qualitative and quantitative, demonstrate that incorporating depth cues into the enhancement process enables the proposed method to outperform comparable Transformer-based and other state-of-the-art deep learning approaches.



Figure 1: Depiction of underwater images affected by different degradation issues

Methodology

In this study, a novel deep learning model is proposed for UIE. The model first generates a depth map of the raw underwater image using an encoder-decoder architecture that combines Transformers' self-attention mechanism with convolutional operations to capture global and local features. The depth map is then concatenated with the raw image and processed by a GAN model to produce the enhanced image. The GAN consists of a Transformer-based encoder-decoder generator and a lightweight CNN discriminator. An overview of the proposed approach is illustrated in Figure 2.

The quality of underwater images decreases with water depth because red light is more readily absorbed than

blue and green light, and suspended particles scatter light. Even if a number of conventional and deep learning-based methods have been put out to improve and restore the image, it is still difficult to produce an upgraded image of excellent quality that retains its natural colour. To address this issue, a novel deep learning architecture is proposed using depth estimation and a transformer-GAN model for UIE. In order to capture the hierarchical features of both raw and monocular depth-estimated image, the suggested network architecture consists of two identical branches.

First, the depth map of an underwater image is obtained

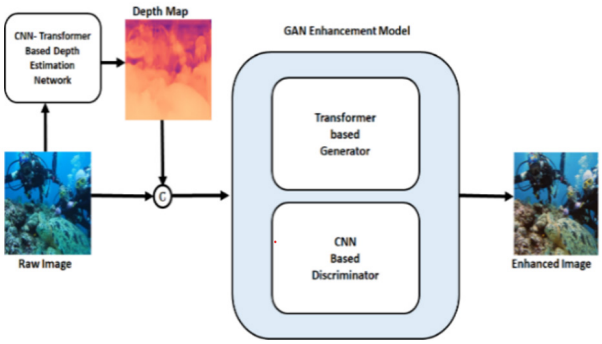


Figure 2: Overview of the proposed approach. The symbol © represents the concatenation operation

using a CNN-Transformer model. Next, the obtained depth map is stacked with the corresponding raw underwater image to incorporate the depth information of the underwater scene as an additional cue as shown in Figure 2. The stacked raw and depth images are then consumed by a GAN model to generate realistic enhanced images. To compute the depth map image (I_u^d) of an underwater image (I_u), the global-local path network model is employed. The Global–Local Path Network, pre-trained on the NYU Depth V2 dataset, was employed to generate depth maps from underwater images.

In Image Enhancement Using Transformer-GAN model, the proposed transformer-GAN model takes the concatenated underwater image and the corresponding reference ground truth image as inputs and generates clean image as output. In this study, the U-shaped transformer model is used as the baseline for designing the architecture of the GAN, and it is modified to process the concatenated underwater image. The generator of the proposed GAN model uses an encoder-decoder architecture. In the first step of the encoding stage, the concatenated input image (I_u^c) is down sampled at three scales: Half-resolution, quarter-resolution, and eighth-resolution, to capture features from high-resolution details to abstract high-level features. Then, the convolutional features of (I_u^d) and the three down sampled images are obtained using corresponding identical convolutional blocks, each consisting of two convolutional layers that use a 3×3 kernel. Then, the features from each convolutional block are fed into a MHA transformer module to improve attention to degraded colour channels across multiple scales. The outputs of the CMHA transformer module are then fed into the corresponding decoder convolutional blocks. Additionally, at the end of the encoder in the generator, a traditional Transformer module is placed between the encoder and decoder as a bottleneck module to capture the global spatial relationships in the image.

The proposed GAN model is trained for a fixed number of iterations. In addition to the standard adversarial loss (L_{GAN}), the multi-colour space loss is utilised to ensure that the enhanced image preserves accurate colour representation in the RGB, LAB, and LCH spaces, as well as visual quality across various perceptual dimensions. The RGB colour space loss (L_{RGB}) is calculated based on the pixel-wise differences between the actual and generated images. The LAB loss (L_{LAB}) comprises two components: luminance loss and categorical cross-entropy loss for the A and B channels. Similarly, the LCH space loss (L_{LCH}) includes two components: luminance loss and saturation and hue losses. In addition to those losses, the well-known perceptual loss (L_{per}) is also included to measure the similarity between high-level features.

The final total loss is measured as:

$$L_{Total} = L_{GAN} + \alpha L_{RGB} + \beta L_{LAB} + \gamma L_{LCH} + \mu L_{per}$$

where α, β, γ, and μ are hyper parameters, which are set experimentally.

The publicly available Large-Scale Underwater Image (LSUI) dataset and Underwater Image Enhancement Benchmark (UIEB) dataset were used to train and evaluate the proposed approach.

Results and Discussion

In this study, raw underwater images and their corresponding monocular depth estimated images are fed to our network architecture to obtain high-quality enhanced images with natural colours. The monocular depth estimation is carried out using the Global-Local Path Networks with the PyTorch framework.

The Structural Similarity Index (SSIM) and Peak Signal-to-Noise Ratio (PSNR) are two full reference quantitative evaluation metrics used in our work. The Underwater Colour Image Quality Evaluation Metric (UCIQE), which takes into account the distinct imaging properties and degradation mechanisms of underwater images, is the metric we have chosen for no-reference quantitative evaluation.

Our model is implemented on a cloud-based Google Colab notebooks with T4 GPU equipped with 15 GB of graphic memory and 50 GB RAM using PyTorch library with Adam optimizer and a learning

rate of 0.0005. A batch size of one is used in training of our network. We compared the proposed method using LUSI dataset with fourteen existing state-of-the-art methods including UIEWD, MMLE, UWCNN, FUnIE, TACL, UIEC^2-Net, U-net, UIE-DAL, UGAN, SCNet, Ucolor, WaterNet, U-Shape Transformer, and Semi-UIR. The depth estimation and a Transformer-GAN based our model achieved PSNR 25.74 and SSIM 0.90, outperforming Semi-UIR (PSNR 25.44, SSIM 0.88), demonstrating improved image fidelity and reduced distortion on the test set of LSUI dataset. Likewise we compared our model using UIEB dataset with three existing state-of-the-art methods including U-net, UGAN, U Shape Transformer. The model recorded PSNR 23.45 and SSIM 0.89, surpassing U-GAN (PSNR 20.71, SSIM 0.82) and U-Shape Transformer (PSNR 21.25, SSIM 0.84), proving its effectiveness in restoring underwater images on the test set of UIEB dataset. The depth estimation model consists of 30.34 million parameters with a complexity of 3.20 GFLOPs, enabling efficient image processing within one second.

Across the majority of evaluation metrics values, our Underwater Image Enhancement Using Depth Estimation and a Transformer-GAN Model outperforms the existing approaches in terms of both image similarity and visual quality.

Conclusion

The proposed Transformer-GAN model leverages Transformer-based feature extraction to capture long-range dependencies and contextual relationships within the image, allowing for more accurate colour restoration and noise reduction. Unlike previous traditional and deep learning-based methods, the depth map of an underwater image was generated and incorporated with raw image features. A Transformer-GAN architecture was then utilised with depth map and degraded image to generate high-quality underwater images with natural colours. The proposed approach was trained and evaluated on publicly available LSUI and UIE benchmark datasets, achieving PSNR values of 25.74 and 23.45 and SSIM values of 0.90 and 0.89, respectively. Experimental results demonstrated that the model outperforms existing methods in terms of colour correction, contrast enhancement, and structural preservation, making it a promising approach for real-world underwater applications.

In conclusion, the Transformer-GAN-based underwater image enhancement and restoration model represents a significant advancement in underwater vision technology, offering a powerful tool for applications in marine exploration, underwater robotics, archaeology, search and rescue missions, and scientific research. The depth maps provide additional cues, as the visibility of underwater images is influenced by the distance of objects from the camera. The use of depth maps further improves the network's understanding of scene structures, leading to more natural and visually appealing results.

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COMPARATIVE ANALYSIS OF MACHINE LEARNING AND DEEP LEARNING FOR CROP YIELD PREDICTION USING MULTI-SOURCE DATA INTEGRATION



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Agriculture plays a vital role in ensuring food security, economic stability, and sustainable development, particularly in developing countries such as Sri Lanka. Accurate crop yield prediction is essential for effective agricultural planning, resource management, and decision-making. However, predicting crop yield remains a challenging task due to the complex interaction of environmental, climatic, soil, and management-related factors. Traditional statistical approaches often fail to capture these nonlinear relationships and dynamic patterns within agricultural datasets.

Recent advancements in Artificial Intelligence (AI), Machine Learning (ML), and Deep Learning (DL) have provided new opportunities for improving agricultural forecasting systems. Machine learning models can identify hidden relationships within structured agricultural datasets, while deep learning techniques are capable of extracting complex temporal and nonlinear patterns from large-scale multi-source data. The integration of agro-meteorological, soil, and crop management data further enhances prediction performance and supports precision agriculture initiatives.

This study focuses on a comparative analysis of machine learning and deep learning approaches for regional crop yield prediction using multi-source agricultural data integration. The research evaluates the performance of several predictive models, including Linear Regression, Support Vector Regression (SVR), Random Forest Regression, Deep Neural Networks (DNN), and Long Short-Term Memory (LSTM) networks. The study aims to identify the most effective model for improving prediction accuracy and supporting data-driven agricultural decision-making.

Traditional crop yield prediction methods are often affected by limited datasets, environmental variability, and the inability to process heterogeneous agricultural information. In contrast, AI-based approaches can process large volumes of structured and unstructured data while identifying significant patterns influencing agricultural productivity. By integrating multiple agricultural data sources, predictive models can generate more reliable and scalable forecasting outcomes for regional crop production.

The proposed study utilizes the “Agriculture Crop Yield” dataset obtained from Kaggle, combined with agro-meteorological variables, soil properties, and crop management factors. The integrated dataset includes parameters such as rainfall, temperature, humidity, soil nutrients, irrigation methods, fertilizer usage, and historical crop production records. Data preprocessing techniques such as missing value handling, normalization, feature engineering, and data transformation are employed to improve data quality and model performance.

Methodology

The methodology of this research consists of data collection, preprocessing, feature engineering, model development, evaluation, and comparative analysis.

Multi-source agricultural datasets are integrated to create a unified dataset suitable for predictive modeling. Data preprocessing techniques are applied to remove inconsistencies, normalize variables, and improve overall data quality.

Several machine learning and deep learning models are implemented and trained using the prepared dataset. Machine learning algorithms such as Linear Regression, Support Vector Regression (SVR), and Random Forest Regression are used as baseline predictive models. Deep learning models including Deep Neural Networks (DNN) and Long Short-Term Memory (LSTM) networks are developed using PyTorch to capture complex nonlinear and temporal relationships within the data.

The models are evaluated using standard performance metrics including Mean Absolute Error (MAE), Mean Squared Error (MSE), Root Mean Squared Error (RMSE), R^2 Score, Precision, Recall, and F1-Score. Hyperparameter tuning and optimization techniques are applied to improve model accuracy and generalization performance. Comparative analysis is conducted to determine the strengths and limitations of each predictive approach.

Additionally, the study explores the applicability of IoT-enabled smart agriculture technologies for real-time agricultural monitoring and forecasting. The proposed system framework considers future deployment possibilities through a Flask API-based architecture to support real-time crop yield prediction and decision support systems.

Results and Discussion

The predictive performance of the Machine Learning (ML) and Deep Learning (DL) models was evaluated using Mean Absolute Error (MAE), Mean Squared Error (MSE), Root Mean Squared Error (RMSE), and the coefficient of determination (R^2 Score). These metrics were selected to comprehensively assess model accuracy, error distribution, and the ability to explain variability in crop yield. The comparative analysis was conducted using a multi-source agricultural dataset integrating agro-meteorological, soil, and crop management information.

The results obtained from the Machine Learning models indicate strong predictive capabilities across all evaluated algorithms. As illustrated in Figure 1, Linear Regression and Support Vector Regression (SVR) achieved R^2 Scores of approximately 0.91, demonstrating their ability to explain more than 90% of the variation in crop yield. However, Random Forest Regression exhibited the most balanced performance, achieving competitive error values while maintaining high predictive accuracy. The superior performance of Random Forest can be attributed to its ensemble learning mechanism, which combines multiple decision trees to reduce variance and improve generalization. Furthermore, Random Forest effectively captures nonlinear relationships among agricultural variables, making it particularly suitable for complex crop production systems where interactions among environmental and management factors are difficult to model using traditional regression techniques.

The findings further reveal that the integration of heterogeneous agricultural data sources significantly enhances prediction performance. Climatic variables such as rainfall, temperature, and humidity, together with soil nutrient characteristics and crop management practices, collectively contributed to improved model accuracy.

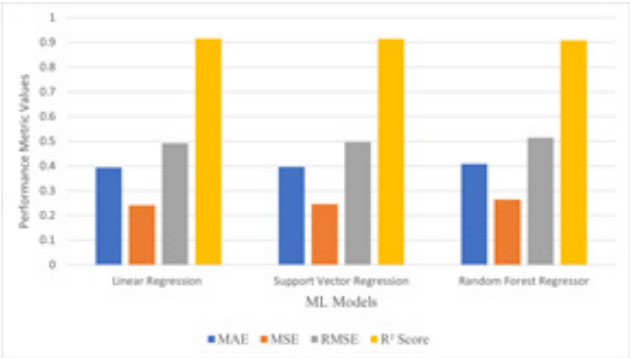


Figure 1: Performance comparison of Machine Learning models for crop yield prediction based on MAE, MSE, RMSE, and R^2 Score

This demonstrates the importance of adopting a multi-source data integration approach rather than relying on individual data categories, as crop productivity is inherently influenced by a combination of environmental and agronomic factors.

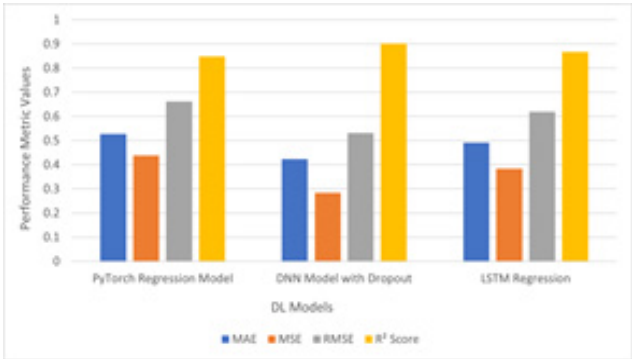


Figure 2: Performance comparison of Deep Learning models for crop yield prediction based on MAE, MSE, RMSE, and R^2 Score

The Deep Learning models demonstrated promising results in handling high-dimensional agricultural datasets characterized by complex nonlinear relationships. As shown in Figure 2, the Deep Neural Network (DNN) with Dropout achieved the highest predictive performance among the evaluated deep learning architectures, recording an R^2 Score of

approximately 0.90 while producing the lowest MAE, MSE, and RMSE values. The incorporation of dropout regularization contributed to reducing overfitting and improving model generalization, enabling the network to learn more robust representations of the underlying agricultural processes.

The LSTM Regression model also produced strong predictive results and outperformed the basic PyTorch Regression model. Although its R^2 Score was slightly lower than that of the DNN model, the LSTM architecture demonstrated a greater capability for capturing temporal dependencies and sequential patterns within the dataset. This characteristic is particularly valuable in agricultural forecasting, where crop yield is influenced by seasonal climatic fluctuations and long-term environmental trends. The ability of LSTM networks to retain historical information allows them to model temporal dynamics more effectively than conventional feedforward neural networks.

A comparison between the Machine Learning and Deep Learning approaches reveals distinct advantages associated with each paradigm. Machine Learning models, particularly Random Forest Regression, provided strong predictive accuracy with relatively low computational requirements and greater interpretability. In contrast, Deep Learning models exhibited a superior capacity to learn complex feature interactions and latent patterns within the integrated dataset. These findings suggest that Deep Learning approaches become increasingly advantageous as the complexity, volume, and diversity of agricultural data increase.

The study also highlights the effectiveness of multi-source data integration for improving crop yield prediction. The inclusion of agro-meteorological variables, soil characteristics, and crop management information enabled the models to capture a broader range of yield-determining factors. Feature importance analysis identified rainfall, temperature, fertilizer application, irrigation practices, and soil nutrient levels as the most influential predictors of crop productivity. These results are consistent with previous studies that emphasize the critical role of environmental and management factors in agricultural production systems.

Overall, the experimental results demonstrate that Artificial Intelligence-based approaches can significantly enhance crop yield forecasting accuracy and support data-driven agricultural decision-making. The developed models provide valuable insights for farmers, agricultural planners, and policymakers by enabling more reliable production forecasts, efficient resource allocation, and proactive risk management. The findings further support the adoption of intelligent predictive systems as a key component of precision agriculture and sustainable food security strategies. Future research will focus on integrating real-time IoT sensor data, remote sensing observations, and hybrid Machine Learning–Deep Learning frameworks to further improve prediction accuracy and operational applicability in smart agriculture environments.

Conclusion

This study demonstrates the effectiveness of Machine Learning and Deep Learning techniques for crop yield prediction using multi-source agricultural data integration. The results showed that integrating agro-meteorological, soil, and crop management data significantly improves prediction accuracy. Among the evaluated models, Random Forest Regression achieved the best performance among Machine Learning approaches, while the Deep Neural Network (DNN) with Dropout provided the highest overall predictive accuracy. The findings highlight the potential of AI-driven forecasting systems to support precision agriculture, improve decision-making, and enhance food security. Future work will focus on incorporating real-time IoT sensor data, satellite imagery, and hybrid AI models to further improve prediction performance and support smart agriculture applications.

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ANATOMICAL, PHYSIOLOGICAL AND EPIGENETIC CHANGES IN *Aedes aegypti* ADAPTING TO SALINITY INNATURE



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Vector-borne diseases account for a substantial proportion of global infectious diseases, with mosquito-borne infections such as dengue posing a major public health burden, particularly in tropical and subtropical regions. Dengue has shown a dramatic increase in incidence over the past two decades, driven by rapid urbanization, climate change, and expansion of mosquito vectors into new ecological niches. *Aedes aegypti*, the primary vector of dengue, is traditionally considered a freshwater-breeding mosquito that thrives in artificial containers such as discarded tires, flower pots, and water storage vessels. However, emerging evidence from coastal regions, including Sri Lanka, indicates that, *Ae. aegypti* is increasingly adapting to brackish water environments. This shift has profound implications for disease transmission dynamics, as it expands the ecological range of the vector into densely populated coastal areas and challenges existing vector control strategies that primarily target freshwater breeding habitats.

The adaptation of mosquito vectors to saline environments has been reported in several regions worldwide and is influenced by environmental pressures such as salinity fluctuations, climate variability, and anthropogenic habitat modification. In Sri Lanka, the presence of salinity-tolerant *Ae. aegypti* in the Jaffna Peninsula has raised concerns regarding the persistence and spread of dengue in coastal communities. Despite these observations, the underlying mechanisms that enable this species to tolerate saline conditions remain poorly understood. In particular, there is limited knowledge regarding the anatomical, physiological, and epigenetic changes that facilitate such adaptation. Understanding these mechanisms is crucial not only for elucidating mosquito ecology but also for developing effective vector control strategies in changing environmental conditions. Therefore, this study aimed to comprehensively investigate the structural, functional, and molecular changes associated with salinity adaptation in *Ae. aegypti*.

Methodology

To achieve this objective, five laboratory colonies of *Ae. aegypti* were established representing different salinity conditions. Two freshwater colonies, JFW and NFW, were maintained in 0 g/L salt, while a brackish water colony, JBW, was reared in 10 g/L salt. Additionally, two reversal colonies were developed to assess the plasticity of adaptation: JFWR (freshwater to brackish water) and JBWR (brackish water to freshwater). These colonies provided a robust experimental framework to evaluate both adaptation and reversibility. A combination of experimental approaches was employed to assess salinity tolerance, reproductive compatibility, insecticide susceptibility, morphological modifications, and epigenetic regulation.

Salinity tolerance was determined by calculating the lethal concentration (LC_{50}) required for larval development from the first instar to adulthood under varying salt concentrations. Reproductive compatibility was evaluated through reciprocal crossing experiments between freshwater and brackish water populations, and egg hatchability was assessed under different salinity conditions. Insecticide susceptibility was examined using standard larval bioassays with temephos and *Bacillus thuringiensis israelensis* (Bti), along with adult bioassays to determine resistance to commonly used insecticides. Enzymatic assays were conducted to quantify the activity of detoxifying enzymes, including esterases, glutathione S-transferases (GSTs), and monooxygenases, which are known to contribute to metabolic resistance.

To investigate structural adaptations, advanced imaging techniques were employed. Atomic force microscopy (AFM) was used to assess surface roughness and elasticity of eggs and larval cuticles, while scanning electron microscopy (SEM) and transmission electron microscopy (TEM) provided detailed insights into ultrastructural changes. Morphometric analyses were performed to measure variations in cuticle thickness, egg morphology, and larval anatomical features. In addition to these physiological and anatomical investigations, epigenetic modifications were explored using chromatin immunoprecipitation (ChIP) followed by quantitative PCR (qPCR) to identify histone modifications associated with salinity adaptation.

Results and Discussion

The findings of this study revealed significant differences between freshwater and brackish water populations of *Ae. aegypti*. Brackish water mosquitoes exhibited a markedly higher tolerance to salinity, with an LC_{50} of approximately 16 g/L compared to 11–12 g/L in freshwater populations. Importantly, this enhanced tolerance was not permanent and could be reversed when environmental conditions were altered, indicating that salinity adaptation is largely driven by phenotypic plasticity rather than fixed genetic changes. This plasticity enables mosquito populations to rapidly respond to environmental fluctuations, thereby facilitating their survival and expansion into new habitats.

Reproductive studies demonstrated that egg hatchability in brackish water conditions was significantly higher when the maternal parent originated from a brackish water population, suggesting maternal inheritance of salinity tolerance traits. This observation indicates the presence of transgenerational effects that may enhance the persistence of adapted populations in saline environments. Similar patterns of adaptation have been reported in other mosquito species, highlighting the role of environmental selection pressures in shaping vector populations.

Structural analyses provided further insights into the mechanisms underlying salinity adaptation. Eggs and larval cuticles of brackish water mosquitoes exhibited increased surface roughness and reduced elasticity, as revealed by AFM measurements. These changes are likely to enhance the mechanical strength of the cuticle and reduce water loss, thereby improving tolerance to osmotic stress. Additionally, adult mosquitoes emerging from brackish water conditions displayed significantly thicker cuticles in the abdomen and tarsal segments. Such modifications not only contribute to environmental resilience but also play a critical role in insecticide resistance by limiting the penetration of toxic compounds.

Consistent with this observation, brackish water mosquitoes showed significantly higher resistance to both larvicides and adulticides. While enzymatic assays indicated that the activities of esterases and GSTs were comparable between freshwater and brackish water populations, a modest increase in monooxygenase activity was observed in brackish water mosquitoes. These results suggest that metabolic detoxification alone does not fully explain the observed resistance. Instead, cuticular resistance mechanisms, driven by structural modifications of the exoskeleton, appear to play a dominant role. This finding has important implications for vector control, as it indicates that conventional insecticide based strategies may be less effective against salinity adapted mosquito populations.

A novel and significant contribution of this study is the identification of epigenetic mechanisms associated with salinity adaptation in *Ae. aegypti*. Chromatin immunoprecipitation analyses revealed differential histone modifications in genes associated with stress response and physiological regulation. These epigenetic changes are likely to influence gene expression patterns, enabling rapid and reversible adaptation to environmental stressors. Unlike genetic mutations, epigenetic modifications do not alter the DNA sequence but can be inherited across generations, providing a flexible mechanism for adaptation. This represents

the first evidence of epigenetic regulation playing a role in salinity tolerance in *Ae. aegypti*, highlighting a previously underexplored aspect of vector biology.

Overall, the results of this study demonstrate that salinity adaptation in *Ae. aegypti* is a complex process involving multiple interacting mechanisms, including phenotypic plasticity, structural modifications, physiological adjustments, and epigenetic regulation. These adaptations enable the mosquito to survive and reproduce in brackish water environments, thereby expanding its ecological niche and increasing the risk of dengue transmission in coastal regions.

Conclusion

In conclusion, this study provides comprehensive evidence that *Ae. aegypti* can adapt to saline environments through a combination of anatomical, physiological, and epigenetic changes. The reversible nature of this adaptation highlights the importance of environmental factors in shaping vector populations. The observed increase in insecticide resistance among brackish water mosquitoes underscores the need to re-evaluate current vector control strategies, which are largely focused on freshwater habitats. Effective control programs must incorporate coastal and brackish water environments and consider alternative approaches that target both larval and adult stages. Furthermore, the identification of epigenetic mechanisms opens new avenues for research into vector adaptation and control. Future studies should focus on identifying specific genes involved in salinity tolerance and exploring the potential for targeting epigenetic pathways as part of integrated vector management strategies.

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