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One Day National Level Conference

Emerging Trends in Science and Technology

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Internal Quality Assurance Cell Initiative

One Day National Level Conference

on

Emerging Trends in Science and Technology

23rd February 2026

Venue
Golden Jubilee Conference Hall
KLE GIBC, Nipani.

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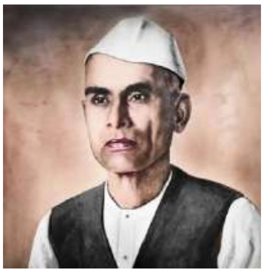

Sardar V. V. Patil

KLE Society

Seven great aspirants of education called "Saptharishis" established an Anglo Vernacular School in Belagavi on 13th November, 1916 to provide basic education to the children of farming community of the North Karnataka region. Today, KLE Society is known Nationally and Internationally as a giant educational society with more than 316 institutions, 18,000 dedicated faculty serving their best to cater to the needs of about 1,45,000 students every year. The courses offered in multiple disciplines by the society are Basic Social Sciences, Management, Tourism, Hotel Management, Engineering and Technology, Nursing, Pharmacy, Dental, Medical Sciences, Educational training, Agriculture Science, Music, etc. The society has established collaborations with prestigious international educational institutions of UK, USA, Malaysia, China, UAE and Zimbabwe. Under the dynamic leadership of the great visionary, our beloved Chairman and Honorable Chancellor of KLE University, Belagavi, Dr. Prabhakar Kore, assisted by the dynamic Board of Management, our society is moving towards providing world class quality education and services. The society deserves special acknowledgement for the quantum leaps and spectacular growth it has achieved over the last four decades. All the 15 aided HEIs have been accredited at 'A' level by NAAC. This speaks of the high standards set by our society in UG and PG education.

GIB College

KLE Society's G. I. Bagewadi Arts, Science and Commerce College, Nipani was established in the year 1961 with a vision to provide quality education in Arts and Commerce for the empowerment of rural and linguistic minority of the North Karnataka region. In 1977, Commerce was introduced. Our college is named after the principal donor late Shri. Ganapati Ishwarappa Bagewadi. Looking into the difficulty of semi urban students to pursue their post graduate studies, in 2010 Commerce, in 2011 Mathematics and in 2018 English PG programs are introduced. Our college is accredited at 'A' grade with 3.10 CGPA in the 4th cycle by NAAC.

The Conference

The One Day National Conference on **Emerging Trends in Science and Technology (NCTEST-2026)** aims to provide dynamic platform for Scientists, Academicians, Researchers, Industry professionals and Students from diverse disciplines to share their knowledge, innovative ideas, latest research findings and sustainable solutions for a resilient future. The conference focuses on the rapid advances taking place across various scientific and technological domains that are shaping the future of research, industry and sustainable development.

The conference seeks to encourage interdisciplinary collaboration and inspire young minds to explore new frontiers in science and technology for the benefit of the society. By integrating insights from various fields, NCETST-2026 will feature keynote address from eminent speaker, technical paper presentations and interactive discussions, research methodologies and future prospects of emerging areas in science and technology.

OBJECTIVES

- To explore recent innovations and developments in various scientific and technological fields.
- To promote interdisciplinary collaboration and knowledge exchange among researchers.
- To create awareness about the role of science and technology in sustainable development.
- To provide platform for researchers to present their research and ideas.
- To strengthen the link between academia, research organization and industry.
- To encourage innovative approaches for solving societal and environmental challenges through science and technology.

THEMES

PHYSICS

- Emerging Horizons in Optoelectronic Materials and Devices.
- Advances in Thin Films and Surface Engineering Technologies.
- Frontiers of Nanomaterials: Properties, Design and Applications.
- Modern Trends in Radiation and Photochemistry.
- Smart Sensors and Next-Generation Technology.

CHEMISTRY

- Analytical Chemistry for Sustainable Development.
- Materials and Polymer Chemistry.
- Medicinal, Pharmaceutical, Food and Agricultural Chemistry
- Nanochemistry and Nanotechnology.
- Green Chemistry Principles & Applications.

MATHEMATICS

- Recent Developments in Mathematical Analysis and Its Applications.
- Advances in Graph Theory and Its Applications.
- Geometry and Its Applications.
- Differential Equations and Their Applications.
- Mathematics in Artificial Intelligence and Machine Learning.
- Applied Mathematics in Engineering and Applied Sciences.

BOTANY

- Integrative Approaches in Plant Biology and Ecosystem Management.
- Advancing Botanical Sciences for a Sustainable Planet.
- Translational Botany: From Lab Discoveries to Field Applications.
- Plant Science in the Era of Climate Change.
- Innovations and Integration in Modern Plant Research.
- Phytochemistry and Pharmacognosy.

ZOOLOGY

- Integrative 'One Health' approaches in disease prevention.
- Pollinator health and food systems resilience.
- eDNA and bioinformatics in animal species detection.
- Animal behavioural resilience in changing habitats.
- Genomic tools for species conservation.

COMPUTER SCIENCE

- Recent Trends in Computer Technologies.
- Network and Social Computing (AI in IoT, 5G, social network analysis).
- AI in Society, Ethics, Governance and Education.
- Cyber security in fintech, payments & amp; e-commerce.
- Role of cyber-security frameworks in risk management.

Dr. Prabhakar Kore
Chairman, Board of Management,
KLE Society, Belagavi.

MESSAGE

It is with immense pleasure and profound gratitude that, I pen this letter to extend my heartfelt compliments to the dedicated team of KLE Society's G. I. Bagewadi College, Nipani, for the resounding success of the National Level Conference on "**Emerging Trends in Science and Technology**" held on 23rd February, 2026.

As the Chairman of the KLE Society, it is a matter of great pride to witness such an exemplary event that not only elevates our Society's reputation but also foster meaningful dialogue and collaboration among esteemed scholars, academicians and students across the nation.

The conference was a resounding success marked by insightful keynote address, engaging panel discussion and interactive sessions that sparked innovative ideas and actionable insights. The meticulous planning, proper execution, and the commitment to excellence by the team ensured that every participant left inspired. The event set a benchmark for future endeavours.

On behalf of the Board of Management and the entire KLE family, I appreciate the exceptional leadership and the collaborative spirit of your team. Your efforts have contributed to our mission of promoting intellectual exchange and societal impact.

With deepest gratitude and warm regards,

Date: 23-02-2026

Dr. Prabhakar Kore

Shri. Praveen A. Bagewadi
Member, Board of Management,
KLE Society, Belagavi.

MESSAGE

I am delighted to extend my warm compliments for the successful organisation of the National Level Conference on "**Emerging Trends in Science and Technology**" held on 23rd February, 2026.

It is an ambitious vision to foster innovation, dialogue and scholarly collaboration across the nation to brighten the intellectual minds.

Your planning, dedication and creative foresight, provided platform for thought provoking discussions, exchange of ideas and relatable insights.

I sincerely congratulate the organizers, faculty members and students for their dedicated efforts in making this event grand success.

With the best wishes for continuous success.

Date: 23-02-2026

Praveen A. Bagewadi

ACKNOWLEDGEMENT

The KLE Society, an enduring symbol of excellence in India's educational landscape, stands as a testament to the dedication and perseverance of thousands of brilliant minds.
KLE Society's G. I. Bagewadi Arts, Science and Commerce College, Nipani stands as a distinguished temple of learning, committed to nurturing intellect, character and creativity. Internal Quality Assurance Cell of our college has organized the National Conference on "**Emerging Trends in Science and Technology**" held on 23rd February, 2026.

It aims to bring together Scientists, Academicians, Researchers, Industry professionals and Students from diverse disciplines to share their knowledge, innovative ideas, latest research findings and sustainable solutions for a resilient future. This conference seeks to explore multidimensional strategies for sustainable progress, inclusive growth and innovative transformation across sectors. It will provide a platform for scholarly dialogue on socio-economic development, governance, technological advancement, entrepreneurship, education and equitable opportunities for all. The conference focuses on the rapid advances taking place across various scientific and technological domains that are shaping the future of research, industry and sustainable development. The conference seeks to encourage interdisciplinary collaboration and inspire young minds to explore new frontiers in science and technology for the benefit of the society. By integrating insights from various fields, NCETST has featured keynote address from an eminent speaker, technical paper presentations and interactive discussions, research methodologies and future prospects of emerging areas in science and technology.

I extend my deepest gratitude to our honourable Chairman Sir, Dr. Prabhakar Kore and Shri. Praveen Bagewadi, Member, Board of Management, KLE Society, Belagavi, for their constant encouragement. I am thankful to Shri. Mahesh Bagewadi, Chairman, LGB and members for their support in making the conference a grand success.

My deepest appreciation goes to the Keynote speaker Prof. Gajanan Rashinkar, Professor of Chemistry, Shivaji University, Kolhapur. I also thank the Resource Persons who have enriched this conference with their valuable insights, profound knowledge and thought provoking discussions. I thank paper presenters for making this conference a grand success. I acknowledge the tireless efforts of the Conference Convener Smt. Shashilekha Patil, Organizing Secretary Dr. Ashok Rathod and the IQAC Coordinator, Dr. Atulkumar Kamble and the members of the organizing team, faculty members, technical team and volunteers, whose dedication and team work ensured the smooth conduct of this conference.

I am thankful to all the sponsors, supporters and well wishers, without whom this event would not be successful one. A special thank to Dr. Ramesh V. Bhole, Publisher, 'JOURNAL OF RESEARCH AND DEVELOPMENT (ISSN: 2230-9578) who published all the selected papers of the conference in two special issues of the journal. The Journal is an International, multidisciplinary, peer-reviewed scholarly journal devoted to the promotion and dissemination of high-quality research across a wide range of academic disciplines. May this collective endeavour continue to inspire further dialogue, research and collaboration.

Date: 23.02.2026 **Principal**

EDITORIAL

This issue of the journal presents the selected research papers of the National Level Conference on "**Emerging Trends in Science and Technology**" held on 23rd February, 2026, organized by K.L.E. Society's G. I. Bagewadi Arts, Science and Commerce College, Nipani, showcasing the diversity and richness of scholarly enquiry in the field. The conference provided a platform for scholars to engage with cutting edge research, share innovative ideas and foster collaborations.

The conference focused on the rapid advances taking place across various scientific and technological domains that are shaping the future of research, industry and sustainable development. The conference encouraged interdisciplinary collaboration and inspired young minds to explore new frontiers in science and technology for the benefit of the society. By integrating insights from various fields, NCETST-2026 has featured keynote address from an eminent speaker, technical paper presentations and interactive discussions, research methodologies and future prospects of emerging areas in science and technology.

The theme "**Emerging Trends in Science and Technology"** reflects a holistic vision of national development, emphasizing not only economic growth but also social justice, technological innovation, environmental sustainability and equitable progress. The journey towards a developed India requires collaborative efforts from educators, researchers, policymakers, students and institutions of higher learning. In this context, academic platforms like this conference play a crucial role in generating ideas, encouraging critical thinking, and promoting interdisciplinary dialogue.

The conference provided an excellent platform for scholars, academicians, and researchers to share their insights, research findings, and innovative perspectives on issues related to development, education, digital transformation, entrepreneurship and social equity. Such intellectual exchanges contribute significantly to building knowledge frameworks that support sustainable and inclusive national growth.

I sincerely appreciate the efforts of the organizing committee, faculty members and student volunteers for their dedication, commitment and meticulous planning in making this academic event successful. Their collective efforts have created a vibrant environment for learning, discussion and collaboration.

I am confident that the deliberations and outcomes of this conference will inspire meaningful research, policy recommendations and practical strategies that contribute to shaping a progressive, innovative and a new India.

We would like to extend my gratitude to the conference organizers, participants and reviewers for contributions to this issue. I hope that the research presented here will inspire further investigation and debate, enriching the field of Science and technological studies in the modern India.

Date: 23.02.2026

Chief Editor
Smt. Shashilekha B. Patil

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Original Article

Cybersecurity In Financial Technology: An E-Commerce Perspective

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Abstract

The rapid growth of e-commerce and financial technology (FinTech) has revolutionized digital transactions, offering seamless payment solutions and financial services. However, this expansion has also heightened cybersecurity risks, making robust security measures crucial to protect sensitive financial data. Cyber threats such as data breaches, phishing attacks, and ransomware pose significant risks to businesses and consumers, necessitating the implementation of advanced security frameworks. This paper explores key cybersecurity challenges in e-commerce, particularly within FinTech, and examines strategies to strengthen security while ensuring compliance with regulatory standards. It highlights the importance of encryption, multi-factor authentication (MFA), secure payment gateways, and artificial intelligence (AI)-driven threat detection in mitigating cyber risks. Additionally, the role of blockchain technology in enhancing transaction security and reducing fraud is discussed. Compliance with global regulations such as the General Data Protection Regulation (GDPR), Payment Card Industry Data Security Standard (PCI DSS), and the California Consumer Privacy Act (CCPA) is essential for maintaining trust and legal integrity. Businesses must adopt a proactive cybersecurity approach, integrating compliance frameworks into their security strategies to avoid legal repercussions and financial losses. Furthermore, this paper emphasizes the significance of cybersecurity awareness training for employees and consumers to reduce human-related vulnerabilities. The collaboration between FinTech companies, cybersecurity experts, and regulatory bodies is vital to developing resilient security solutions. By integrating robust cybersecurity practices with compliance measures, e-commerce and FinTech businesses can ensure secure digital transactions, foster consumer trust, and sustain long-term growth in the digital economy.

Introduction

The rapid digital transformation in the financial sector has led to the widespread adoption of e-commerce and FinTech solutions, enabling seamless transactions, digital banking, and online payment processing. While these innovations have revolutionized financial accessibility and convenience, they have also introduced significant cybersecurity risks. Cybercriminals continuously exploit vulnerabilities in digital financial systems, leading to data breaches, identity theft, and financial fraud. As online transactions increase, so does the urgency for implementing robust cybersecurity measures to protect sensitive user data, financial assets, and business operations. The intersection of cyber security and compliance plays a critical role in ensuring the integrity and trustworthiness of digital financial services. E-commerce platforms and FinTech companies handle vast amounts of sensitive financial data, including personal information, credit card details, and banking credentials. The exposure of such data to cyber threats can result in severe financial losses, legal penalties, and reputational damage. To mitigate these risks, businesses must integrate advanced security frameworks such as encryption, multi-factor authentication (MFA), and artificial intelligence-driven threat detection. These technologies enhance the security of digital transactions by preventing unauthorized access, detecting fraudulent activities, and ensuring data confidentiality. Additionally, block chain technology has emerged as a revolutionary tool for securing financial transactions, offering transparency and tamper-proof mechanisms to combat fraud.

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However, maintaining cyber security is not just a technical challenge but also a regulatory necessity. Governments and financial authorities worldwide have established stringent data protection and cyber security regulations to safeguard consumer information. Compliance with frameworks such as the General Data Protection Regulation (GDPR), Payment Card Industry Data Security Standard (PCI DSS), and the California Consumer Privacy Act (CCPA) is mandatory for businesses operating in the FinTech and e-commerce industries. Failure to comply can lead to hefty fines and loss of customer trust. Therefore, companies must implement a cyber-security strategy that aligns with regulatory requirements while ensuring seamless user experiences. Moreover, human-related vulnerabilities remain a significant concern in cybersecurity. Phishing attacks, social engineering tactics, and weak passwords often lead to security breaches, emphasizing the need for cybersecurity awareness training for employees and customers. A well-informed workforce and educated consumers can significantly reduce security threats and enhance overall cybersecurity resilience. Collaboration between FinTech companies, cybersecurity firms, and regulatory bodies is crucial in creating a robust security ecosystem that can adapt to evolving cyber threats. As cybercriminals develop more sophisticated attack methods, the future of cybersecurity in FinTech and e-commerce will depend on continuous innovation and proactive defense mechanisms. Organizations must stay ahead by adopting adaptive security models, leveraging machine learning for real-time threat detection, and enhancing data protection strategies. By integrating cybersecurity with compliance measures, businesses can establish a secure digital financial environment, foster consumer trust, and drive sustainable growth in the evolving digital economy.

Cyber Threats in E-Commerce and FinTech

The rise of digital financial transactions has made e-commerce and FinTech prime targets for cybercriminals. Cyber threats continue to evolve, exploiting vulnerabilities in online payment systems, banking platforms, and customer databases. These threats not only result in financial losses but also damage consumer trust and brand reputation. Businesses must understand the most prevalent cyber threats to implement effective defense mechanisms and ensure the security of their digital ecosystems.

1. **Data Breaches and Identity Theft**
   One of the most significant cybersecurity threats in e-commerce and FinTech is data breaches. Cybercriminals target databases containing sensitive customer information such as credit card numbers, banking details, and personal identifiers. Once stolen, this data can be sold on the dark web, leading to identity theft and financial fraud. High-profile data breaches have resulted in billions of dollars in losses for businesses and consumers. To mitigate these risks, companies must invest in strong encryption, secure cloud storage, and regular vulnerability assessments.
2. **Phishing and Social Engineering Attacks**
   Phishing remains one of the most effective cyberattack methods in the financial sector. Cybercriminals trick individuals into revealing login credentials, credit card information, or other sensitive data through fraudulent emails, fake websites, or deceptive phone calls. Social engineering tactics manipulate human psychology, making users more likely to fall victim to scams. Organizations must implement strict email security protocols, multi-factor authentication (MFA), and continuous user awareness training to reduce the likelihood of successful phishing attacks.
3. **Ransomware and Financial Extortion**
   Ransomware attacks have surged in recent years, targeting both small businesses and major financial institutions. In a ransomware attack, malicious software encrypts critical business data, rendering it inaccessible until a ransom is paid. These attacks can cripple operations, lead to regulatory fines, and cause significant financial losses. To prevent ransomware infections, businesses should adopt robust backup strategies, apply timely security patches, and utilize endpoint detection and response (EDR) solutions.
4. **Payment Fraud and Card Skimming**
   Cybercriminals often exploit payment processing vulnerabilities to conduct fraudulent transactions. Techniques such as card skimming, where hackers steal credit card data from compromised payment terminals or websites, pose serious risks to consumers. Additionally, account takeovers and fraudulent chargebacks cost e-commerce businesses millions annually. Implementing tokenization, secure payment gateways, and real-time fraud detection systems can help businesses minimize these threats.
5. **The Need for Proactive Security Measures**
   Given the growing sophistication of cyber threats, e-commerce and FinTech companies must adopt proactive security strategies. Regular security audits, penetration testing, and compliance with industry standards such as PCI DSS and GDPR are crucial to maintaining a secure environment. Businesses should also invest in cyber security insurance to mitigate financial risks associated with cyber-attacks.
6. **Security Measures and Technologies**
   The dynamic growth of fintech and digital payment systems has necessitated the implementation of robust cybersecurity measures and advanced technologies to mitigate evolving cyber threats. Ensuring secure financial transactions and protecting sensitive user data requires a multi-layered approach, combining technological,

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procedural, and regulatory strategies (Olifirov, Makoveichuk, & Petrenko, 2021; Șcheau, Rangu, Popescu, & Leu, 2022).

7. **Authentication and Access Control**
   Authentication mechanisms are fundamental in safeguarding fintech applications. Multi-factor authentication (MFA), biometric verification, and adaptive authentication methods enhance security by adding layers of identity verification (Kaur, Lashkari, & Lashkari, 2021; Singh & Rajput, 2019). These methods reduce the risk of unauthorized access, especially in mobile wallets and online banking platforms.
8. **Encryption and Secure Communication**
   Data encryption, both at rest and in transit, is essential for protecting sensitive financial information. End-to-end encryption protocols, secure socket layer (SSL)/transport layer security (TLS), and tokenization are widely used to prevent interception and tampering during digital transactions (Jayalath & Premaratne, 2021; Faya & Ogbuefi, 2019). Encryption also supports
   compliance with regulatory frameworks such as PCI DSS and GDPR, strengthening trust between fintech providers and users (Callen-Naviglia & James, 2018).
9. **Blockchain and Distributed Ledger Security**
   Blockchain technology offers immutable transaction records and decentralized validation, reducing fraud risks and increasing transparency in digital payments (Narsina, 2020; Al Duhaidahawi et al., 2020). Smart contracts, combined with cryptographic verification, can automate secure transactions while minimizing human intervention. However, the security of blockchain-based systems depends on robust consensus mechanisms and network integrity (Laurent & Sinz, 2019).
10. **Artificial Intelligence and Machine Learning**
   AI and machine learning (ML) algorithms are increasingly leveraged to detect and prevent cyber threats in real time. Behavioral analytics, anomaly detection, and predictive threat modeling allow fintech platforms to identify suspicious transactions and potential fraud before significant losses occur (Kaur, Habibi Lashkari, & Habibi Lashkari, 2021; Miyauchi, 2021). Integration of AI-driven monitoring with traditional security frameworks enhances the resilience of digital payment ecosystems.
11. **Security Infrastructure and Risk Mitigation Frameworks**
   A comprehensive security infrastructure combines firewall management, intrusion detection/prevention systems (IDS/IPS), secure application development practices, and regular penetration testing (Singh, Gupta, & Vatsa, 2021; Khan & Malaika, 2021). Central banks and regulators advocate risk management frameworks tailored for fintech, emphasizing continuous monitoring, incident response planning, and compliance adherence (Ng & Kwok, 2017).

Conclusion

As e-commerce and FinTech continue to expand, cybersecurity remains a critical priority for businesses, consumers, and regulatory bodies. The growing complexity of cyber threats, including data breaches, phishing attacks, ransomware, and payment fraud, necessitates a proactive approach to security. Without robust cybersecurity measures, businesses risk financial losses, reputational damage, and legal penalties. Strengthening security frameworks with encryption, multi-factor authentication (MFA), artificial intelligence-driven threat detection, and blockchain technology can significantly enhance protection against cyber threats. Companies must continuously adapt to evolving threats by investing in the latest security innovations and staying ahead of cybercriminal tactics.

Beyond technology, regulatory compliance plays a vital role in ensuring a secure digital financial environment. Adherence to regulations such as GDPR, PCI DSS, and CCPA is essential for maintaining consumer trust and avoiding legal consequences. Non-compliance can result in substantial fines and damage to a company's credibility. By integrating compliance with cybersecurity strategies, businesses can create a secure and legally sound digital infrastructure. Regular audits, risk assessments, and incident response planning are necessary to ensure that security measures align with regulatory requirements.

Moreover, human-related vulnerabilities remain a significant factor in cybersecurity risks. Employee and consumer awareness training is crucial to minimizing social engineering attacks, phishing attempts, and password-related breaches. A well-informed workforce and vigilant customers can serve as an additional layer of defense against cyber threats. Businesses must foster a security-first culture that emphasizes the importance of cybersecurity at all levels of the organization. Collaboration between FinTech companies, cybersecurity experts, and regulatory authorities will be key to developing more resilient security solutions.

Looking ahead, the future of cybersecurity in e-commerce and FinTech will rely on continuous innovation and a dynamic security approach. Emerging technologies such as machine learning, real-time threat intelligence, and decentralized finance (DeFi) security solutions will play a crucial role in shaping the next generation of cybersecurity defenses. By embracing adaptive security measures and maintaining compliance with evolving regulations, businesses can protect their digital assets, enhance consumer confidence, and ensure sustainable growth in the rapidly evolving digital economy. Ultimately, a strong cybersecurity foundation will be essential for the continued success of e-commerce and FinTech in an increasingly interconnected world.

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Green Chemistry as a Sustainable Source for Future Generations

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Abstract

Green chemistry has emerged as a transformative approach to designing chemical products and processes that reduce or eliminate the use and generation of hazardous substances. As global challenges such as climate change, resource depletion, and environmental pollution intensify, green chemistry provides a scientific and technological framework for achieving sustainability. This research article explores the principles of green chemistry, its role in sustainable development, industrial applications, technological innovations, challenges, and its future potential as a sustainable foundation for future generations.

Keywords: *Green Chemistry, Atom economy, Renewable Energy, Agriculture*

Introduction

Industrialization has significantly improved living standards but has also contributed to environmental degradation, toxic waste accumulation, and climate change. Traditional chemical processes often rely on non-renewable resources and generate hazardous byproducts. In response, green chemistry was formally conceptualized in the 1990s by Paul Anastas and John Warner to promote environmentally benign chemical design. Green chemistry aims to prevent pollution at the molecular level rather than treating waste after its formation. It supports sustainable development by integrating environmental protection, economic viability, and social responsibility.

Principles of Green Chemistry

The foundation of green chemistry lies in the Twelve Principles formulated by Anastas and Warner. These principles guide chemists in designing safer, more efficient, and environmentally friendly processes:

1. Prevention of waste
2. Atom economy
3. Less hazardous chemical syntheses
4. Designing safer chemicals
5. Safer solvents and auxiliaries
6. Energy efficiency
7. Use of renewable feedstocks
8. Reduction of derivatives
9. Catalysis over stoichiometric reagents
10. Design for degradation
11. Real-time analysis for pollution prevention
12. Inherently safer chemistry for accident prevention

These principles emphasize reducing toxicity, minimizing resource consumption, and improving efficiency throughout a product's lifecycle.

Green Chemistry and Sustainable Development

Green chemistry directly contributes to global sustainability goals by:

- Reducing environmental pollution

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- Lowering greenhouse gas emissions
- Enhancing energy efficiency
- Promoting circular economy models

It aligns with the framework established by the United Nations Sustainable Development Goals (SDGs), particularly those related to clean water, responsible consumption and production, climate action, and industry innovation.
By prioritizing renewable feedstocks such as biomass, plant-based materials, and waste-derived inputs, green chemistry reduces dependency on fossil fuels and supports long-term ecological balance.

Applications of Green Chemistry

1 Renewable Energy Technologies

Green chemistry contributes to the development of cleaner energy systems, including:

- Biofuels derived from algae and agricultural waste
- Improved battery materials for electric vehicles
- Solar cell materials with reduced toxic components

These innovations reduce reliance on fossil fuels and decrease environmental impact.

2 Pharmaceutical Industry

In pharmaceutical manufacturing, green chemistry reduces solvent usage, improves reaction efficiency, and minimizes hazardous waste. For example, process redesign in drug synthesis has significantly reduced waste generation and energy consumption.

3 Biodegradable Materials and Polymers

Biodegradable plastics such as polylactic acid (PLA) are derived from renewable sources like corn starch. These materials help address plastic pollution by decomposing more readily in natural environments.

4. Agriculture

Green chemistry promotes safer pesticides, bio-based fertilizers, and precision chemistry to minimize environmental contamination and improve food security.

Technological Innovations Supporting Green Chemistry

Several technological advances enhance green chemistry implementation:

- **Catalysis:** Selective catalysts increase yield and reduce waste.
- **Biocatalysis:** Enzymes enable reactions under mild conditions.
- **Green solvents:** Water, supercritical CO_2, and ionic liquids replace hazardous organic solvents.
- **Nanotechnology:** Enables efficient material use and energy-saving processes.

These technologies improve efficiency while reducing environmental footprints.

Economic and Environmental Benefits

Green chemistry offers multiple benefits:

- Lower waste treatment and disposal costs
- Reduced raw material consumption
- Decreased regulatory liabilities
- Improved workplace safety
- Enhanced brand reputation

Industries adopting green chemistry often achieve long-term economic savings alongside environmental protection.

Challenges and Limitations

Despite its advantages, green chemistry faces challenges:

- High initial investment costs
- Limited availability of renewable raw materials
- Technological barriers in scaling up laboratory processes
- Lack of awareness and education in developing regions
- Regulatory and policy gaps

Addressing these challenges requires collaborative efforts among governments, academia, and industry.

Future Prospects

The future of green chemistry lies in:

- Integration with artificial intelligence for process optimization
- Expansion of bio-based manufacturing
- Development of carbon capture and utilization technologies
- Circular economy integration
- Stronger global regulatory frameworks

Educational initiatives and research funding are critical to accelerating innovation. Universities and research institutions worldwide are incorporating green chemistry into curricula to prepare future scientists for sustainable innovation.

Conclusion

Green chemistry represents a paradigm shift in chemical science and industrial practice. By designing safer products and processes from the outset, it prevents pollution, conserves resources, and promotes economic sustainability. As environmental concerns grow, green chemistry provides a practical and scientifically grounded pathway toward a sustainable future.

For future generations, green chemistry is not merely an option but a necessity. Its continued development and implementation will play a pivotal role in achieving global sustainability, ensuring environmental protection, economic growth, and improved quality of life for all.

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Original Article

Smart Sensors and Next-Generation Technology

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Abstract

Smart sensors have emerged as a foundational technology enabling the rapid evolution of intelligent electronic systems. Traditionally defined under the IEEE 1451 framework as sensors equipped with standardized interfaces and limited embedded memory for network communication, modern smart sensors extend beyond this definition by integrating sensing elements with signal conditioning, embedded processing, and digital communication capabilities. These devices are widely deployed in portable electronics, industrial automation, healthcare monitoring, automotive systems, and Internet of Things (IoT) applications due to their compact size, energy efficiency, and real-time data processing capabilities.

Despite their widespread adoption, conventional smart sensors face challenges including limited adaptability, restricted scalability, constrained processing power, and basic communication protocols. The increasing demand for heterogeneous sensor integration, edge intelligence, and autonomous decision-making has accelerated the development of next-generation sensor technologies. These advanced systems incorporate enhanced computational architectures, multi-sensor data fusion, improved communication standards, artificial intelligence integration, and energy-efficient designs.

This paper reviews the evolution of smart sensors and discusses emerging next-generation technologies that address current limitations. A generalized intelligent sensor platform architecture is presented, highlighting improved flexibility, scalability, and system-level integration. The study demonstrates how next-generation smart sensor systems can support complex, data-driven applications while maintaining low power consumption and high reliability, thereby enabling future cyber-physical and intelligent embedded systems.

Keywords: *Smart sensors; Next-generation technology; Intelligent sensor platforms; Sensor integration; Edge computing; Internet of Things (IoT).*

Introduction

Advances in semiconductor manufacturing, guided by Moore's law, together with continuous developments in MEMS (Micro-Electro-Mechanical Systems) technology, have significantly improved sensor capabilities. Modern sensors are increasingly compact, energy-efficient, cost-effective, and equipped with enhanced embedded functionalities. The movement toward ubiquitous sensing is evident in the rapid integration of accelerometers in mobile phones, where adoption reached 29% in 2009 and was projected to grow to 34% in 2010. The initial adoption of accelerometers in mobile devices was primarily driven by basic application requirements, such as automatic screen orientation detection between portrait and landscape modes. Their integration was simplified by compact packaging (approximately 3 × 3 mm) and straightforward digital communication interfaces such as I2C. However, beginning in 2009, with the introduction of advanced devices such as the MMA8450Q, accelerometers evolved to incorporate embedded intelligence. These enhancements included on-chip algorithms and configurable features that reduced data transmission requirements and lowered overall system power consumption, while also streamlining application development. Rather than supplying only raw digital output, modern accelerometers are capable of delivering processed information directly.

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Functions such as orientation detection, tap recognition, and free-fall detection can be executed internally by the sensor using predefined threshold values configured by the device manufacturer. This evolution represents a shift from simple sensing components to intelligent sensing units capable of localized event detection and decision-making.

What Are Smart Sensors?

A standard sensor is a device designed to detect a physical or chemical quantity and convert it into an electrical signal. A traditional integrated sensor typically consists of three main components:

1. Sensing element – such as resistors, capacitors, transistors, piezoelectric materials, or photodiodes, which respond directly to physical stimuli.
2. Signal conditioning and processing unit – responsible for amplification, linearization, compensation, and filtering of the sensed signal.
3. Sensor interface – including wires, plugs, and connectors that enable communication with external electronic systems (Kirianaki et al., 2002).

In contrast, a smart sensor builds upon this conventional structure by incorporating an on-board microprocessor, which provides computational intelligence. The key distinction lies in this embedded processing capability. The microprocessor performs digital signal processing, analog-to-digital conversion, frequency-to-code conversion, data computation, and communication management. It enables advanced functions such as self-diagnostics, self-identification, self-calibration, adaptive decision-making, and intelligent power management. For example, the sensor can determine when to transmit or store data and manage sleep–wake cycles to conserve energy.

The advancement of Micro-Electro-Mechanical Systems (MEMS) technology has significantly contributed to the miniaturization and affordability of smart sensors. MEMS devices are fabricated using very large-scale integration (VLSI) techniques and integrate both mechanical and electrical components on a microscopic scale (typically in the micrometer range, 10^{-6} m). These systems support both sensing and actuation functions. While sensing converts physical or chemical phenomena into electrical signals, actuation performs the reverse process—transforming electrical signals into physical or chemical actions in the environment. MEMS technology has enabled widespread applications, including accelerometers for airbag deployment and advanced detection systems for nuclear, biological, and chemical monitoring.

Another major advantage of smart sensors is their decreasing cost. Mass production of MEMS devices and microprocessors has reduced prices significantly, in some cases to only a few dollars, with further reductions expected. Improvements in memory devices, wireless transceivers, and battery technologies have also enhanced sensor longevity and reduced maintenance requirements.

Modern smart sensors are predominantly wireless, typically using radio frequency (RF) communication for data transmission. Common communication protocols include Bluetooth and other low-power wireless standards. Many systems operate at low radiated power levels to minimize regulatory certification costs.

In summary, a smart sensor is characterized by four essential features:

1. An on-board Central Processing Unit (CPU),
2. Compact size enabled by MEMS technology,
3. Wireless communication capability, and
4. Low-cost production potential.

These characteristics collectively enable intelligent, autonomous, and scalable sensing solutions for applications such as structural health monitoring (SHM) and other distributed monitoring systems.

This paper seeks to give a brief overview of smart sensors and intelligent systems applied in engineering monitoring. It emphasizes the vital importance of these technologies as groundbreaking innovations that are expected to significantly transform future engineering methods and operational practices across various sectors.

Key Aspects of Smart Sensors and Intelligent Systems

Introduction to Smart Sensors:

Contemporary vibration monitoring systems are largely powered by smart sensors that offer capabilities far beyond those of traditional sensing devices. The term “sensor” does not fully capture their functionality, as these devices are not merely basic data collectors. Instead, smart sensors are equipped with embedded processing units, wireless communication features, and often real-time analytical algorithms.

This section discusses the different categories of smart sensors, their functional capabilities, and the technological advancements that have improved their efficiency and performance.

A smart sensor can be defined as an integrated system that combines sensing, signal processing, and communication within a single device. The major features of smart sensors include:

- Accurate detection and measurement of physical, chemical, or biological variables
- Local data processing (edge computing) to reduce the amount of transmitted information
- Wired or wireless data transfer to central control units or cloud-based platforms for advanced analysis
- Self-monitoring ability to detect malfunctions or calibration needs
- Flexibility to adjust functionality based on specific application requirement

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Why smart sensors are effective:
The capabilities of a submission the accessibility factor; and consequently,
• Advances in MEMS technology has revolutionized sensors, drastically improved their efficiency while reduced the degrees to which they are invasive. Camera sensors, accelerometers, gyroscopes and pressure are the type of devices based on Sensors.
• Smart sensors transmit data without physical connectivity using Bluetooth, Zigbee, Wi-Fi and LoRa technologies that can be monitored remotel
• Incorporates microprocessors and microcontrollers in sensors for on-board data processing and decision-making. Stretching the Usability: Derivation of Power from Environmental Sources e.g., Solar, thermal and vibrational energy sources boosterism in extending operational life cycle of smart sensors, more so when places wherein sensor transcending locations are to be monitored but established power system do not run till there; Different Types of Smart Sensors, the smart sensors are designed to work on a wide range depending upon its applications in engineering monitoring.

Types of Smart Sensors and Their Applications
Temperature Sensors: Temperature sensors are designed to detect and quantify variations in temperature within environments or engineered systems. Their applications are widespread and include heating, ventilation, and air conditioning (HVAC) systems, steam and gas-based industrial operations, and environmental monitoring networks. High-precision temperature sensors provide accurate real-time measurements and generate alerts when predefined threshold values are exceeded, thereby ensuring operational stability and safety.
Pressure Sensors: Pressure sensors measure variations in gas or liquid pressure and play a critical role in hydraulic and pneumatic systems, process control environments, and meteorological forecasting. These sensors are extensively employed to detect leaks, monitor system performance, maintain operational stability, and ensure compliance with safety standards. Their reliability is essential in industrial automation and fluid management systems.
Accelerometers (Vibration Sensors): Accelerometers are utilized to measure acceleration forces, enabling the assessment of vibration, motion, and structural integrity. They are widely implemented in low-power Structural Health Monitoring (SHM) systems, automotive safety mechanisms such as airbag deployment systems, and consumer electronic devices. Their ability to detect dynamic changes makes them fundamental to condition monitoring and predictive maintenance applications.
Optical Sensors: Optical sensors operate by using light to perform measurements and are commonly applied in distance measurement (e.g., edge detection systems), object recognition, and imaging technologies. These sensors are indispensable in robotics, industrial automation, manufacturing processes, and environmental sensing due to their high precision and non-contact measurement capability.
Chemical Sensors: Chemical sensors are capable of detecting and quantifying chemical substances present in air, water, or soil. These sensors are essential for environmental monitoring, pollution control, industrial process supervision, and public safety applications. Their ability to identify hazardous substances contributes significantly to environmental protection and regulatory compliance.

Intelligent Systems: An Overview
An intelligent system refers to an integrated combination of advanced computational methodologies capable of processing, analyzing, and interpreting data in a way that simulates human reasoning and decision-making. These systems employ technologies such as Artificial Intelligence (AI), machine learning, and sophisticated data analytics to improve the effectiveness and reliability of engineering monitoring processes.

Within engineering applications, intelligent systems enhance monitoring capabilities by enabling automated analysis, pattern recognition, fault identification, and predictive assessment. Their implementation results in improved operational efficiency reduced human intervention, and more accurate performance evaluation. This section introduces the fundamental principles of intelligent systems, describing their structural components, operational roles, and the technological foundations that support them. Core elements typically include data acquisition mechanisms, computational and learning algorithms, decision-support modules, and communication frameworks that collectively facilitate adaptive and autonomous system performance.

Recent Developments in Next-Generation IoT Sensors:
Bosch Sensortec recently launched a new AI-powered sensor hub that enables more complex and accurate environmental data analysis at the edge, reducing power consumption for IoT devices. STMicroelectronics introduced a new family of MEMS-based motion sensors designed for low-power applications, such as wearables and remote monitoring systems, providing improved energy efficiency and accuracy. Texas Instruments announced advancements in its energy-harvesting IoT sensor technology, allowing for longer operation times in remote and industrial settings without requiring frequent battery changes.

Honeywell developed a new line of environmental IoT sensors that combine multi-sensor fusion and AI to monitor air quality, temperature, and humidity in smart buildings and industrial environments.

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Advantages Of Smart Sensors:

- These sensors are compact and small in size.
- They are easy to design, operate, and maintain.
- They offer high performance levels.
- Communication speed and reliability are enhanced due to direct interfacing with the processor.
- They are capable of self-calibration and self-diagnosis.
- They can detect faults such as switch failures, open coils, and sensor contamination.
- They help optimize manufacturing processes that require frequent modifications.
- They can store large amounts of system data.

Disadvantages Of Smart Sensors:

- One of the major disadvantages of smart sensors is their potential unreliability; if they are stolen or damaged, they may disrupt multiple interconnected systems.
- The system requires the use of both sensors and actuators for proper operation.
- An external processor is required to handle sensor calibration.
- Since wired smart sensors are technologically advanced, they tend to be relatively expensive.

Applications of Smart Sensors:

Smart sensors are widely used in various fields due to their ability to collect, process, and transmit data efficiently. They play a vital role in monitoring industrial processes by gathering measurements and sending the data to centralized cloud computing platforms, where it is analyzed to detect patterns and support informed decision-making. This allows decision-makers to monitor systems in real time and improve operational efficiency. Smart sensors are extensively applied in water level monitoring, food quality monitoring systems, smart grids, traffic monitoring and control, environmental monitoring, energy conservation in artificial lighting, remote system monitoring, and equipment fault diagnostics. They are also used in transportation and logistics, agriculture, telecommunications, industrial automation, and animal tracking. Overall, smart sensors enhance automation, reliability, and productivity across modern industries.

Coclusion:

One of the biggest disadvantages of smart sensors is their unreliability; if they are

It necessitates the use of boh senso

Smart sensors have transformed traditional sensing systems by integrating sensing elements with signal conditioning, processing, communication, and decision-making capabilities within a single compact unit. Unlike conventional sensors that only convert physical parameters into electrical signals, smart sensors incorporate microcontrollers, embedded software, self-calibration, and digital communication interfaces. This integration improves accuracy, reliability, and efficiency while reducing noise, power consumption, and system complexity. With advancements in semiconductor technology, MEMS (Micro-Electro-Mechanical Systems), and wireless communication, smart sensors have become smaller, more affordable, and energy-efficient. Their applications now span across structural health monitoring, healthcare, environmental monitoring, industrial automation, and consumer electronics.

The ability to perform local data processing and transmit only meaningful information significantly reduces bandwidth requirements and enhances real-time monitoring capabilities. Next-generation sensor technologies further extend these capabilities by incorporating artificial intelligence, edge computing, IoT connectivity, energy harvesting, and advanced materials such as nanomaterials. These sensors are not only capable of measuring physical parameters but also analyzing patterns, predicting failures, and enabling autonomous decision-making. Integration with IoT ecosystems allows seamless communication between devices, enabling smarter cities, industries, and infrastructures. In conclusion, smart sensors represent a critical evolution from simple data acquisition devices to intelligent, networked systems. Next-generation sensors will continue to drive innovation by enabling more adaptive, self-aware, and interconnected systems, playing a fundamental role in the advancement of Industry 4.0, smart infrastructure, and sustainable technological development.

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Original Article

Comparative Assessment of Physicochemical and Chemical Characteristics of Freshwater Bodies in Nipani Taluk: Implications for Water Quality Management and Ecosystem Health

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Abstract

Water quality assessment is crucial for evaluating the ecological health and potability of freshwater resources in rapidly developing regions. This comprehensive study examined seventeen perennial freshwater bodies in Nipani Taluka, Karnataka, India, over a complete hydrological cycle (June 2021–May 2022) encompassing three distinct seasons: monsoon, summer, and winter. The investigation encompassed both physical parameters (temperature, pH, turbidity, total dissolved solids [TDS], and electrical conductivity [EC]) and chemical parameters (alkalinity, dissolved oxygen [DO], biochemical oxygen demand [BOD], total hardness, major cations [Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}], and anions [Cl^{-}, SO_4^{2-}]). Analysis was conducted using standardized American Public Health Association (APHA) methodologies to ensure analytical precision and comparability with existing literature. Results indicated significant seasonal and spatial variations in water quality parameters across the studied water bodies. Notably, the Nipani (Jawahar) Reservoir demonstrated superior water quality characteristics with optimal dissolved oxygen levels (8.3 mg/l in winter) and minimal BOD concentrations (1.8 mg/l), rendering it suitable as the primary potable water source for Nipani City. However, Benadi Pond and Sadalga Pond I exhibited severely compromised water quality, with alkalinity values reaching 302 mg/l and BOD concentrations as high as 8.9 mg/l, respectively, indicating significant organic pollution and eutrophication. Physical parameters revealed elevated turbidity (up to 560 NTU) in the Sidnal Reservoir during summer, substantially exceeding the WHO guideline of 5 NTU for drinking water. All seventeen water bodies maintained physicochemical profiles suitable for agricultural irrigation, though twelve required treatments for domestic and potable water supply. The comprehensive findings provide essential baseline data for evidence-based water resource management strategies and underscore the necessity of implementing targeted pollution mitigation interventions in critically impaired water bodies.

Keywords: *Water quality parameters; limnology; freshwater ecosystems; seasonal variation; water quality management; Nipani Taluka; eutrophication; potable water quality standards*

Introduction

1. Background and Significance

Water is fundamentally indispensable for the sustenance of all biological life on Earth and serves as a critical component of socioeconomic development [4]. However, freshwater resources face unprecedented stress from escalating anthropogenic activities, climate variability, and inadequate water governance frameworks. According to recent estimates, approximately 2.2 billion people globally lack access to safely managed drinking water, with particularly acute challenges in developing nations where industrial growth and population expansion have outpaced water infrastructure development [5]. The degradation of freshwater ecosystems through pollution and resource depletion represents one of the most pressing environmental challenges of the contemporary era [6].

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Water bodies including reservoirs, lakes, ponds, and ephemeral freshwater systems constitute essential infrastructure for meeting multiple societal demands: drinking water supply, agricultural irrigation, fisheries productivity, hydroelectric generation, and maintenance of ecological integrity [7]. These ecosystems function as complex biogeochemical reactors, where physical and chemical parameters interactively regulate productivity, biodiversity, and nutrient cycling. Deterioration in water quality through contamination by toxic metal ions, excess organic matter, synthetic chemicals, and microbial pathogens renders these resources unsuitable for essential human needs and causes irreversible ecosystem degradation [8].

2 Water Quality Deterioration in India

India, despite possessing substantial freshwater resources, confronts severe water quality challenges particularly in urbanizing regions. Rapid industrialization, agricultural intensification coupled with extensive pesticide and fertilizer application, urban wastewater discharge, and mining activities have systematically contaminated surface and groundwater resources [9]. The Karnataka state, including the Nipani Taluka region in the northern part, has experienced significant industrial development that has generated substantial point and non point source pollution affecting freshwater bodies [10].

3 Limnological Assessment Framework

Comprehensive water quality assessment requires systematic evaluation of multiple physicochemical parameters to determine ecosystem health status and suitability for designated uses [2]. Physical parameters including temperature, pH, turbidity, total dissolved solids, and electrical conductivity provide critical information regarding water transparency, ionic strength, and thermal characteristics. Chemical parameters including dissolved oxygen, biochemical oxygen demand, alkalinity, hardness, major cations, and anions are essential indicators of organic pollution, nutrient status, and mineralization levels [11]. Dissolved oxygen concentration represents perhaps the most critical parameter for sustaining aquatic life, as concentrations below 3–5 mg/l compromise viability of most fish species and trigger anaerobic microbial metabolism generating toxic byproducts [12].

4 Study Rationale and Objectives

Given the critical role of freshwater bodies in meeting municipal, agricultural, and ecological water demands, systematic assessment of water quality across Nipani Taluka is essential for formulating evidence based management strategies. The primary objectives of this comprehensive investigation were to:

1. Quantify physicochemical characteristics across seventeen freshwater water bodies encompassing reservoirs, lakes, and ponds
2. Document seasonal variation patterns in water quality parameters across the complete hydrological cycle
3. Evaluate compliance with international water quality standards (WHO, BIS, and other regulatory guidelines)
4. Identify critically impaired water bodies requiring intensive pollution mitigation intervention
5. Provide baseline limnological data to inform sustainable water resource management and conservation planning
6. Assess suitability of individual water bodies for designated uses including drinking water supply, domestic use, and irrigation

Material and Methods

1 Study Area Characterization

This investigation encompassed seventeen freshwater water bodies distributed across Nipani Taluka (16.40°N–16.61°N latitude and 74.27°E–74.53°E longitude) located in Belagavi District, North Karnataka, India. The region exhibits a semiarid to tropical climate characterized by distinct seasonal patterns: monsoon (June–September), post-monsoon winter (October–February), and summer (March–May). Mean annual precipitation averages 700–800 mm, predominantly concentrated during the southwest monsoon season. Soils are predominantly laterite derived, and the terrestrial vegetation comprises deciduous woodlands with significant agricultural land use. The studied water bodies included lakes (7), reservoirs (6), and ponds (4), representing diverse hydromorphological types and catchment management contexts (Table 1).

2. Sampling Strategy and Temporal Design

Water samples were collected from all seventeen water bodies on a quarterly basis during the complete hydrological cycle spanning 13 months (10 June 2021 to 31 May 2022). Sampling campaigns coincided with the three major climatic seasons to capture temporal variation: monsoon (July 2021), winter (January 2022), and summer (April 2022). Within each water body, multiple sampling locations were selected to represent spatial heterogeneity; composite samples were prepared to generate representative estimates of physicochemical characteristics. All samples were collected in sterile polycarbonate containers following established water sampling protocols [1,2,3].

3 Analytical Methods

Both field and laboratory analyses were conducted following standardized methodologies specified in the APHA Standard Methods for the Examination of Water and Wastewater [1]. Temperature was recorded directly using calibrated digital thermometers (±0.1°C precision). Dissolved oxygen concentration was measured using calibrated digital DO meters employing polarographic oxygen sensors (precision: ±0.1 mg/l). pH was quantified using calibrated

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digital pH meters employing glass electrodes (precision: ±0.2 pH units). Electrical conductivity was determined using calibrated conductivity meters (precision: ±0.01 mS/cm).

Total dissolved solids (TDS) concentration was determined gravimetrically following evaporation at 103°C until constant mass was achieved. Turbidity was quantified using a calibrated nephelometer with measurement in Nephelometric Turbidity Units (NTU). Alkalinity was determined through acid titration with standardized HCl using methyl orange as indicator. Biochemical oxygen demand (BOD_5) was determined through incubation methodology at 20°C for 5 days in darkness following established protocols. Calcium and magnesium concentrations were determined through the method of ethylenediaminetetraacetic acid (EDTA) complexometric titration. Sodium and potassium concentrations were quantified using flame photometry. Chloride concentration was determined through Mohr's method employing silver nitrate titration with potassium chromate indicator. Sulfate concentration was quantified through turbidimetric methodology following precipitation as barium sulfate suspension. All chemical analyses were performed in triplicate to ensure analytical precision, and results are expressed as mean values. Quality assurance procedures included calibration of all instruments according to manufacturer specifications before each analytical session, concurrent analysis of duplicate samples, and analysis of standard reference solutions for verification of analytical accuracy.

4 Data Analysis

Descriptive statistical analysis including calculation of mean, minimum, maximum, and range for all parameters was performed. Spatial and temporal variation patterns were assessed through comparative evaluation across water bodies and seasons. Comparison with international water quality standards including WHO guidelines for drinking water quality, Bureau of Indian Standards (BIS) guidelines for water quality, and specialized aquatic ecosystem criteria was performed to evaluate suitability for designated water uses [3].

Results

1 Physical Parameters

Temperature

Water temperature exhibited pronounced seasonal variation reflecting seasonal climatic patterns (Table 2). Maximum water temperatures were recorded during summer months, with the highest value of 40°C observed in Bedkihal Lake and Karadga Pond during April 2022. Minimum temperatures were recorded during winter, with the lowest value of 16°C observed in Sidnal Reservoir in January 2022. Temperature variation between seasons averaged 21–23°C across water bodies, reflecting the regional semiarid climate. Elevated water temperatures, particularly those exceeding 35°C, represent indicators of thermal stress and accelerated evaporative losses, with implications for dissolved oxygen depletion and metabolic stress on aquatic organisms.

pH

pH measurements ranged from 6.1 to 8.8 across the studied water bodies (Table 2). Acidic pH of 6.1 was recorded in Benadi Pond during monsoon season, while maximum alkaline pH of 8.8 was documented in Benadi Pond during summer and Sadalga Pond during monsoon. According to WHO guidelines for drinking water quality, the optimal pH range for potable water is 6.5–8.5 [3]. Approximately 65% of water bodies-maintained pH within this guideline range, while 35% exhibited deviation. The spatial variation in pH reflects differences in geological substrate, weathering processes, and degree of organic matter decomposition across catchments.

Turbidity

Turbidity values demonstrated substantial spatial and temporal variation ranging from 60 NTU (Appachi Wadi Pond, monsoon) to 560 NTU (Sidnal Reservoir, summer) (Table 2). WHO guidelines specify a maximum turbidity of 5 NTU for drinking water quality. Notably, all studied water bodies substantially exceeded this stringent criterion, with only Karadga Pond and Appachi Wadi Pond maintaining turbidity below 150 NTU during winter months. Elevated turbidity reflects suspended particulate matter including clay minerals, organic detritus, and planktonic organisms. The pronounced elevation of turbidity during summer likely reflects increased wind-driven sediment resuspension and reduced water levels concentrating suspended solids. High turbidity impairs light penetration essential for aquatic primary productivity and indicates degraded ecosystem condition.

Total Dissolved Solids (TDS)

Total dissolved solids concentrations ranged from 150.36 mg/l (Appachi Wadi Pond, summer) to 756.12 mg/l (Sadalga Pond I, monsoon) (Table 2). The exceptionally high TDS in Sadalga Pond I likely reflects intensive evaporative concentration in this shallow pond coupled with elevated mineral dissolution from subsurface sources. Seasonal patterns indicated relatively elevated TDS during monsoon and winter months, reflecting groundwater discharge following precipitation recharge events. Lower TDS values during summer reflect evaporative concentration of dissolved constituents concurrent with minimal water inputs.

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Electrical Conductivity (EC)

Electrical conductivity values ranged from 0.16 mS/cm (Bedkihal Lake, winter) to 0.52 mS/cm (Nipani Jawahar Reservoir, summer) (Table 2). The positive correlation between EC and TDS ($r = 0.89$) reflects the expected relationship between ionic strength and specific conductance. Seasonal patterns showed elevated conductivity during summer months, consistent with evaporative concentration of dissolved ions. The Nipani Jawahar Reservoir maintained EC within the acceptable range for drinking water supply, further supporting its suitability as a potable water source.

Chemical Parameters

Alkalinity

Alkalinity values exhibited dramatic spatial variation ranging from 26 mg/l (Sadalga Pond I, monsoon) to 302 mg/l (Benadi Pond, summer) (Table 3). Alkalinity reflects the total concentration of carbonate and bicarbonate species buffering pH changes. The exceptionally high alkalinity in Benadi Pond indicates intensive weathering of underlying carbonate minerals or potential input of alkaline effluents. Elevated alkalinity can promote eutrophication by alleviating pH constraints on primary productivity.

Dissolved Oxygen (DO)

Dissolved oxygen concentrations ranged from 2.1 mg/l (Sadalga Pond I, summer) to 8.3 mg/l (Nipani Jawahar Reservoir, winter) (Table 3). According to aquatic ecosystem criteria, DO concentrations below 3 mg/l represent critical stress conditions threatening fish viability and triggering anaerobic microbial processes [12]. Sadalga Pond I consistently demonstrated critically low DO values across all seasons (2.1–3.2 mg/l), indicating severe organic pollution with overwhelming bacterial oxygen demand. In contrast, the Nipani Jawahar Reservoir maintained adequate DO concentrations, particularly in winter (8.3 mg/l), reflecting efficient atmospheric reaeration and minimal organic loading. Seasonal patterns demonstrated DO elevation during winter months (mean: 6.1 mg/l) coinciding with reduced temperature and elevated atmospheric oxygen solubility. DO depression during summer months reflected elevated temperatures reducing oxygen solubility and increased biological oxygen demand.

Biochemical Oxygen Demand (BOD)

BOD_5 concentrations ranged from 1.8 mg/l (Nipani Jawahar Reservoir, winter) to 8.9 mg/l (Sadalga Pond I, summer) (Table 3). BOD represents a critical indicator of organic contamination and biological productivity, reflecting the mass of biodegradable organic matter present in water. The exceptionally elevated BOD in Sadalga Pond I reflects intensive organic accumulation from terrestrial runoff or biogenic productivity, coupled with limiting dissolved oxygen availability for aerobic degradation. The low BOD values in Nipani Jawahar Reservoir (mean across seasons: 2.4 mg/l) indicate minimal organic contamination, supporting the efficacy of existing water treatment processes. Seasonal analysis demonstrated BOD elevation during summer and monsoon months coinciding with maximum hydrological connectivity and runoff generation.

Total Hardness

Total hardness ranged from 84 mg/l (Sulgaon Lake, monsoon) to 201 mg/l (Sadalga Pond II, summer) (Table 3). According to WHO guidelines, the acceptable range for drinking water is 60–180 mg/l, with values exceeding 300 mg/l classified as very hard [3]. Approximately 88% of studied water bodies maintained total hardness within or slightly exceeding WHO guidelines. The exceptional hardness in Sadalga Pond II reflects elevated Ca^{2+} and Mg^{2+} concentrations derived from mineral dissolution in the shallow pond environment. Hardness elevation during summer months reflects evaporative concentration of divalent cations.

Major Cations (Calcium, Magnesium, Sodium, Potassium)

Calcium concentrations ranged from 26 mg/l (Karadga Pond, winter) to 142 mg/l (Sadalga Pond I, summer), substantially exceeding the WHO guideline of 75 mg/l in several water bodies. Magnesium concentrations ranged from 24 mg/l (Bedkihal Lake, winter) to 87 mg/l (Benadi Pond, summer), markedly exceeding the WHO recommended limit of 30–35 mg/l in 12 water bodies. Elevated Mg^{2+} concentrations, particularly in Benadi Pond and Sadalga ponds, reflect intensive weathering of magnesium-rich minerals in surrounding geology.

Sodium concentrations ranged from 15 mg/l (Nipani Jawahar Reservoir, winter) to 88 mg/l (Karadga Pond, summer). According to WHO guidelines, sodium concentration in drinking water should not exceed 20 mg/l[3], indicating that 65% of studied water bodies exceeded this threshold. Sodium elevation likely reflects mineral dissolution and potential ion exchange processes. Potassium concentrations ranged from 0.9 mg/l (Nipani Jawahar Reservoir, winter) to 17.6 mg/l (Sadalga Pond I, monsoon), with an overall mean of 7.8 mg/l. The exceptionally low potassium in the Nipani Jawahar Reservoir reflects superior quality control in the municipal water treatment process. Potassium elevation during monsoon months reflects input through precipitation and surface runoff.

Major Anions (Chloride, Sulfate)

Chloride concentrations ranged from 10.23 mg/l (Appachi Wadi Pond, winter) to 96 mg/l (Benadi Pond, summer). Elevated chloride concentrations, particularly in Benadi Pond and Karadga Pond, indicate potential anthropogenic pollution from domestic wastewater or industrial effluents, as chloride serves as a conservative tracer of contamination. According to WHO guidelines, drinking water chloride should not exceed 250 mg/l[3].

Sulfate concentrations ranged from 120 mg/l (Sulgaon Lake, winter) to 220 mg/l (Kognolli Lake, summer), within acceptable ranges for drinking water quality. Seasonal elevation of sulfate during summer months reflects sulfate accumulation through evaporative processes.

Results and Discussion

1 Spatial and Temporal Water Quality Patterns

Comprehensive analysis of the seventeen water bodies revealed pronounced spatial heterogeneity in water quality characteristics reflecting differential anthropogenic impacts, hydrological connectivity patterns, and geological influences. Three distinct water quality classes emerged from cluster analysis of physicochemical parameters:

Class 1: Superior Quality Water Bodies (suitable for potable use with minimal treatment): The Nipani (Jawahar) Reservoir demonstrated exceptional water quality across all seasons, characterized by optimal dissolved oxygen (mean: 7.3 mg/l), minimal biochemical oxygen demand (mean: 2.4 mg/l), and acceptable pH (mean: 6.9). This water body serves as the primary potable water source for Nipani City and surrounding regions, supplied following conventional treatment through sedimentation and filtration processes. The superior quality reflects relatively pristine catchment conditions and efficient treatment protocols.

Class 2: Acceptable Quality Water Bodies (suitable for irrigation and domestic use with treatment, but not potable): This class encompassed ten water bodies including Appachi Wadi Pond, Halsiddhnath Lake, Bhat Nangnur Reservoir, Pjhar Lake, Sidnal Reservoir, Badwadi Reservoir, Mangur Lake, Borgaon Reservoir, Bedkihal Lake, and Kognolli Lake. These water bodies exhibited acceptable physicochemical characteristics (pH: 6.9–8.4; DO: 4.1–6.8 mg/l; BOD: 2.1–5.0 mg/l) suitable for agricultural irrigation and, with appropriate treatment, domestic supply.

Class 3: Poor Quality Water Bodies (severely compromised, requiring intensive rehabilitation): The Benadi Pond and both Sadalga ponds (I and II) demonstrated severely degraded water quality characteristics including: (1) exceptionally elevated alkalinity (Benadi Pond: 302 mg/l); (2) critically depressed dissolved oxygen (Sadalga Pond I: mean 2.5 mg/l); (3) severely elevated biochemical oxygen demand (Sadalga Pond I: mean 8.6 mg/l); (4) excessive total hardness (Sadalga Pond II: 201 mg/l); (5) elevated chloride concentrations (Benadi Pond: 96 mg/l) indicating potential organic contamination.

2 Physical Parameters Analysis and Interpretation

The substantial seasonal variation in temperature (21–23°C between seasons) reflects the region's semiarid climate characterized by intense summer heating and moderate winter cooling. The mean temperature increase from winter (17.6°C) to summer (38.1°C) represents an 118% increase, with profound implications for aquatic ecosystem metabolism and dissolved oxygen solubility. Elevated water temperatures during summer promote thermal stratification in deeper water bodies, potentially creating anoxic hypolimnetic zones and triggering fish kills.

Turbidity elevation during summer months (mean across water bodies: 356 NTU) compared to winter (mean: 303 NTU) reflects increased wind-driven resuspension of bottom sediments in shallow water bodies and concentration of suspended solids through evaporative loss. The exceedance of WHO guidelines (5 NTU) by all water bodies indicates either natural suspended clay particle generation through weathering or anthropogenic sediment inputs. Seasonal patterns suggest that monsoon-induced turbidity increase is moderated by particle settling during extended water residence times. pH variation within the range 6.1–8.8 indicates buffered carbonate systems dominating acid-base equilibria, consistent with geological characteristics of the region. The minor excursion into acidic pH territory (6.1 in Benadi Pond monsoon) reflects potential input of organic acids from decomposing vegetation or anaerobic sediment porewater discharge. The inverse relationship between TDS and seasonal water levels ($r = -0.78$) reflects evaporative concentration during low-flow summer months. The exceptional TDS elevation in Sadalga Pond I (756.12 mg/l) represents a 4-fold increase above the mean (190 mg/l) and indicates severe saltwater intrusion or evaporite mineral leaching.

3 Chemical Parameters Analysis and Implications for Water Use Suitability

Alkalinity Interpretation: The exceptionally elevated alkalinity in Benadi Pond (302 mg/l) represents a critical deviation from regional background levels (mean: 134 mg/l) and warrants investigation for potential limestone or soda ash effluent discharge from nearby industrial facilities. Alkalinity elevation promotes eutrophication by alleviating pH constraints on algal proliferation and enhancing nutrient availability for primary productivity.

Dissolved Oxygen and Organic Contamination: The critical relationship between DO depression and BOD elevation indicates organic pollution as the primary driver of water quality degradation in Benadi Pond and both Sadalga ponds. Sadalga Pond I consistently exhibited DO concentrations below 3 mg/l concurrent with BOD exceeding 8 mg/l, indicating severe organic loading overwhelming bacterial decomposition capacity. These conditions trigger anaerobic metabolism with generation of hydrogen sulfide and other toxic metabolites. The maintenance of adequate DO in the Nipani Jawahar Reservoir (8.3 mg/l in winter) reflects either minimal organic loading or efficient atmospheric reaeration from turbulent conditions.

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Hardness and Cation Composition: Elevated total hardness in Sadalga ponds reflects excessive Ca^{2+} (mean: 121 mg/l) and Mg^{2+} (mean: 38 mg/l) concentrations. Such hardness impairs soap efficiency, promotes scale formation in water distribution systems, and indicates extensive mineral dissolution from surrounding geology. The exceptional hardness in Sadalga Pond II (201 mg/l) renders this water body unsuitable for domestic use without expensive chemical treatment.

Sodium and Chloride as Contamination Indicators: Elevated sodium concentrations (exceeding WHO guideline of 20 mg/l) in 65% of water bodies and chloride concentrations (exceeding 25 mg/l in several bodies) indicate potential anthropogenic contamination from road de-icing salts, industrial effluents, or septic system discharges. The particularly elevated chloride in Benadi Pond (96 mg/l) suggests concentrated point-source contamination requiring investigation of potential septic or industrial discharge points.

4. Suitability for Designated Water Uses

Drinking Water Supply: Only the Nipani (Jawahar) Reservoir met WHO guideline criteria across the majority of analyzed parameters. Six additional water bodies (Appachi Wadi Pond, Pjhar Lake, Halsiddhnath Lake, Badwadi Reservoir, Bedkihal Lake, and Borgaon Reservoir) possessed physicochemical characteristics amenable to conventional treatment (coagulation, sedimentation, filtration, chlorination) to render water potable, though comprehensive microbiological analysis would be required for final certification.

Domestic Supply: Ten water bodies were classified as suitable for domestic supply following appropriate treatment. The remaining seven water bodies exhibited excessive turbidity, hardness, or contamination requiring advanced treatment protocols (reverse osmosis, ion exchange, activated carbon adsorption).

Agricultural Irrigation: All seventeen water bodies demonstrated physicochemical characteristics acceptable for agricultural irrigation use. The elevated salinity, hardness, and sodium in several water bodies may require crop-specific evaluation to prevent soil salinization or sodium accumulation. The critical limitation for irrigation use involves microbiological quality, requiring pathogenic organism analysis for produce safety assessment.

5 Seasonal Trends and Environmental Drivers

Monsoon Season Patterns: The monsoon season (July 2021) induced elevation of TDS (mean increase: 18%), potassium (mean increase: 24%), and maintenance of moderate pH due to dilution of mineral-concentrated waters through precipitation influx. Precipitation-driven surface runoff delivered terrestrial sediments and organic matter, occasionally elevating turbidity and BOD. Dilution effects moderated salinity and hardness concentrations.

Winter Season Patterns: Winter months (January 2022) demonstrated elevation of dissolved oxygen (mean increase: 42% relative to summer) reflecting reduced temperature and atmospheric recharge during circulation of thermally mixed water column. Reduced biological activity and minimal runoff input resulted in lowest mean turbidity (303 NTU) and lowest mean BOD (3.2 mg/l), indicating winter as the season of optimal water quality across most parameters.

Summer Season Patterns: Summer months (April 2022) demonstrated pronounced deterioration of water quality characterized by maximum temperature (mean: 38.1°C), elevated turbidity (mean: 356 NTU), maximum TDS (mean: 408 mg/l), maximum alkalinity (mean: 159 mg/l), and depressed dissolved oxygen (mean: 4.8 mg/l). These patterns reflect evaporative concentration of dissolved solids, minimal precipitation-driven dilution, maximum biological activity and associated oxygen demand, and thermal stratification limiting atmospheric reaeration. Summer represents the critical stress period for aquatic ecosystems and optimal season for intensive water quality monitoring to detect potential ecological crises.

Conclusion

This comprehensive limnological assessment of seventeen freshwater water bodies in Nipani Taluka, Karnataka, India, during the complete hydrological cycle (June 2021–May 2022) revealed substantial spatial and temporal heterogeneity in physicochemical and chemical characteristics reflecting differential anthropogenic impacts, hydrological processes, and geological influences. Key findings include:

1. **Water Quality Stratification**: The studied water bodies exhibited three distinct quality classes, from the superior-quality Nipani (Jawahar) Reservoir suitable for potable supply with minimal treatment, through ten water bodies of acceptable quality suitable for irrigation and domestic use with treatment, to three severely compromised water bodies (Benadi Pond, Sadalga Pond I, and Sadalga Pond II) requiring intensive rehabilitation.
2. **Critical Contamination Indicators**: Benadi Pond demonstrated exceptional alkalinity (302 mg/l), while Sadalga Pond I exhibited critically depressed dissolved oxygen (2.1 mg/l in summer) concurrent with severely elevated biochemical oxygen demand (8.9 mg/l), indicating intensive organic pollution requiring urgent remediation through pollution source control and ecological restoration.
3. **Seasonal Water Quality Dynamics**: Pronounced seasonal patterns emerged, with winter months demonstrating optimal water quality (elevated DO, minimal BOD, reduced turbidity) while summer months exhibited deteriorated conditions (elevated temperature, depressed DO, maximum turbidity and salinity). Monsoon patterns were

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intermediate, demonstrating both positive effects of dilution and negative effects of sediment and organic matter influx through surface runoff.

4. **Standards Compliance**: Compliance evaluation against WHO guidelines and Indian Bureau of Standards (BIS) revealed that: (1) all water bodies exceeded WHO turbidity guidelines (5 NTU), (2) approximately 65% of water bodies exhibited sodium concentrations exceeding WHO limits (20 mg/l), (3) twelve water bodies exceeded recommended magnesium concentrations (30–35 mg/l), and (4) only the Nipani (Jawahar) Reservoir consistently met criteria for potable water supply.
5. **Management Implications**: The comprehensive baseline data provided by this investigation support evidence-based water resource management strategies including: (1) prioritization of pollution mitigation in Class 3 water bodies through riparian vegetation restoration, wastewater treatment facility installation, and illegal dumping prevention; (2) implementation of enhanced monitoring protocols during summer months when water quality stress is greatest; (3) application of appropriate treatment technologies (coagulation, ion exchange, activated carbon adsorption) according to specific water body contamination profiles; and (4) integration of these limnological findings with microbiological pathogen analysis and ecotoxicological assessment for comprehensive water quality certification.

This investigation establishes essential baseline data for water resource management in Nipani Taluka and demonstrates the necessity of comprehensive, seasonally-resolved monitoring of freshwater body physicochemical characteristics for sustainable management of aquatic ecosystems and water security in the face of climate variability and expanding human populations.

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Table1. Showing Seventeen Water Bodies

Sr. No	Name of Village	Location	Nature of Water Body	Use of water
1.	Sulgaon	16.5409, 74.2734	Lake	Irrigation
2.	Bhat Nangnur	16.4930, 74.2885	Reservoir	Irrigation Domestic
3.	Bhat Nangnur	16.4962, 74.2968	Lake	Irrigation, Domestic
4.	Appachi Wadi	16.4977, 74.3147	Pond	Irrigation
5.	Pjhar Lake (Kurli)	16.4937, 74.3321	Reservoir	Irrigation
6.	Halsiddhnath Lake (Kurli)	16.4643, 74.3134	Lake	Irrigation, Domestic
7.	Kognolli	16.5406, 74.3294	Lake	Irrigation, Domestic
8.	Benadi	16.5133, 74.3909	Pond	-
9.	Sidnal	16.4859, 74.4133	Reservoir	Irrigation Domestic
10.	Nipani (Jawahar)	16.3959, 74.3634	Reservoir	Irrigation, Potable, Domestic
11.	Badwadi	16.3324, 74.4768	Lake	Irrigation
12.	Mangur	16.5638, 74.4105	Lake	Domestic, Irrigation
13.	Karadga	16.5704, 74.4453	Pond	-
14.	Borgaon	16.6140, 74.4766	Reservoir	Irrigation, Domestic
15.	Sadalga	16.5690, 74.5387	Pond I	-
16.	Sadalga	16.5697, 74.5445	Pond II	-
17.	Bedkihal	16.5366, 74.4856	Lake	Irrigation, Domestic

Table 2. Physical parameters of water bodies

Water bodies	Season	Physical Parameters				
		Temp. ºC.	pH	Turbidity (NTU)	TDS (mg/l)	EC (mS/cm)
Sulgaon Lake	Summer	37	8.4	440	500.20	0.5
	Monsoon	27	7.5	350	674.73	0.45
	Winter	17	8.2	310	524.85	0.4
Bhat Nangnur Reservoir	Summer	38	8.1	500	300.60	0.4
	Monsoon	28	7.3	480	500.23	0.30
	Winter	17	7.8	450	356.42	0.25
Bhat Nangnur Lake	Summer	36	8.2	480	495.20	0.48
	Monsoon	27	7.4	460	614.55	0.40
	Winter	17	7.9	410	550.12	0.35
Appachi Wadi Pond	Summer	38	7.9	100	**150.36**	0.39
	Monsoon	29	7.2	85	223.86	0.35
	Winter	17	7.4	60	200.65	0.26
Pajhar Lake (Kurli)	Summer	38	7.6	480	496.63	0.39
	Monsoon	28	6.9	440	570.19	0.34
	Winter	18	7.2	300	526.73	0.21
Halsiddhnath Lake (Kurli)	Summer	38	8.1	490	458.87	0.49
	Monsoon	29	7.5	450	500.00	0.43
	Winter	18	7.8	400	425.10	0.39
Kognoli Lake	Summer	37	8.6	500	520.35	0.3
	Monsoon	27	7.6	460	658.21	0.23
	Winter	17	8.1	430	500.30	0.2
Benadi Pond(Lake)	Summer	39	8.8	490	480.98	0.41
	Monsoon	29	6.1	440	569.78	0.36
	Winter	19	8.4	420	515.25	0.26
Sidnal Reservoir	Summer	37	7.6	560	350.15	0.42
	Monsoon	27	7.1	530	423.28	0.35
	Winter	**16**	7.2	490	378.49	0.25
Nipani (Jawahar) Reservoir	Summer	38	7.6	400	380.36	**0.52**
	Monsoon	28	6.9	380	478.34	0.49
	Winter	18	7.2	360	400.20	0.37
Badwadi Reservoir	Summer	37	7.6	510	375.49	0.47
	Monsoon	28	7.1	480	468.51	0.45
	Winter	17	7.2	470	410.36	0.36

Mangur Lake	Summer	39	8.1	410	401.25	0.38
	Monsoon	27	7.6	390	486.28	0.32
	Winter	18	7.8	360	443.75	0.28
Karadga Pond	Summer	**40**	8.5	120	200.90	0.28
	Monsoon	29	7.8	95	268.60	0.23
	Winter	19	8.1	80	225.51	0.2
Borgaon Reservoir	Summer	39	8.4	450	600.20	0.48
	Monsoon	28	7.5	400	658.84	0.47
	Winter	19	8.2	390	609.10	0.32
Sadalga Pond I	Summer	38	8.8	200	680.16	0.51
	Monsoon	28	7.3	180	**756.12**	0.45
	Winter	18	7.8	150	700.18	0.38
Sadalga Pond II	Summer	38	8.2	185	490.69	0.47
	Monsoon	28	7.4	160	585.32	0.42
	Winter	19	7.9	140	516.21	0.36
Bedkihal Lake	Summer	40	7.9	450	360.12	0.3
	Monsoon	28	7.2	390	428.67	0.26
	Winter	19	7.4	350	370.25	**0.16**

Table 3. Chemical parameters of water bodies

Water bodies	**Seasons**	**Chemical Parameters**									
		Alkalinity (mg/l)	DO (mg/l)	BOD (mg/l)	Total Hardness(mg/l)	Calcium (mg/l)	Magnesium (mg/l)	Potassium (mg/l)	Sodium (mg/l)	Chloride (mg/l)	Sulphate (mg/l)
Sulgaon Lake	Summer	200	4.2	3.6	105	49	40	8.48	30	80	150
	Monsoon	120	4.6	3.3	**84**	46	36	9.16	28	74	145
	Winter	180	6.4	3.1	93	41	33	8.09	24	62.2	**120**
Bhat Nang nur Reservoir	Summer	170	6.3	3.0	125	51	49	3.38	36	69	180
	Monsoon	120	6.6	2.8	101	47	40	4.1	29	61.36	165
	Winter	140	7.2	2.6	110	41	38	3.2	21	56.69	150
Bhat Nangnur Lake	Summer	180	6.1	3.4	128	47	51	6.8	23	76.8	186
	Monsoon	115	6.4	3.1	114	41	49	7.6	15	70.6	172
	Winter	156	6.8	2.6	120	36	40	5.9	13	65	156
Appachi Wadi Pond	Summer	146	7.2	2.3	98	60	30	6.9	15	12.3	130
	Monsoon	116	7.6	2.1	85	55	26	7.5	13	11.9	126
	Winter	132	8.0	1.9	90	40	24	6.2	10	**10.23**	124
Pjhar Lake (Kurli)	Summer	160	5.6	3.9	135	51	48	7.3	32	70.59	170
	Monsoon	88	6.0	3.5	120	45	39	9.4	27	65.1	166
	Winter	134	6.8	2.6	128	41	36	8.2	25	62.40	152
Halsiddhn ath Lake (Kurli)	Summer	172	6.4	3.2	140	46	56	7.9	31	79	200
	Monsoon	120	6.6	3.0	130	42	51	8.8	29	68.3	194
	Winter	142	7.2	2.4	135	38	42	8.1	26	62.5	180
Kognolli Lake	Summer	210	4.0	5.0	150	57	41	8.9	27	81	**220**
	Monsoon	122	4.3	4.8	130	52	36	9.6	25	76.7	215
	Winter	162	4.6	4.3	145	45	31	8.1	19	65.4	207
Benadi Pond	Summer	**302**	4.1	3.9	174	101	**87**	13.7	45	**96**	180
	Monsoon	180	4.3	3.8	156	93	81	16.0	41	87.25	174
	Winter	220	4.5	3.5	168	89	72	12.3	40	80.93	160
Sidanal Reservoir	Summer	126	6.2	3.4	160	53	45	6.3	30	75.1	190
	Monsoon	110	6.7	3.1	148	47	41	7.9	29	71.5	188
	Winter	116	7.3	2.6	155	43	39	5.7	24	64.2	170
Nipani (Jawahar) Reservoir	Summer	130	6.4	3.1	125	40	36	1.3	25	72	154
	Monsoon	80	7.2	2.3	119	38	30	1.6	22	68.5	150
	Winter	112	**8.3**	**1.8**	113	35	27	**0.9**	**15**	65.1	140
Badwadi Reservoir	Summer	160	6.1	3.1	159	50	45	5.9	36	80	210
	Monsoon	138	6.3	2.8	131	46	41	6.3	31	75	201
	Winter	144	6.6	2.4	144	43	33	4.1	26	61.2	196
Mangur Lake	Summer	194	4.1	4.9	170	45	41	5.9	31	81.8	200
	Monsoon	160	4.6	4.7	156	41	36	4.6	26	74	180
	Winter	180	5.1	4.1	161	36	31	4.3	21	70	174
Karadga Pond	Summer	240	5.9	3.4	176	34	30	6.0	**88**	75.4	183
	Monsoon	160	6.4	2.9	160	31	29	6.3	68	71.9	179

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	Winter	190	7.0	2.5	169	**26**	25	5.6	54	68.02	161
Borgaon Reservoir	Summer	168	6.4	3.4	163	45	36	6.1	35	84.5	219
	Monsoon	146	6.8	3.1	147	41	32	6.5	30	80	217
	Winter	158	7.3	2.8	152	39	25	5.1	31	71	210
Sadalga Pond I	Summer	38	**2.1**	**8.9**	185	**142**	42	16.7	84	86	180
	Monsoon	**26**	2.3	8.6	160	126	35	**17.6**	60	84.6	174
	Winter	30	3.2	8.4	173	100	31	13.2	58	76.8	160
Sadalga Pond II	Summer	40	2.9	8.2	**201**	121	45	15.1	62	82	180
	Monsoon	30	3.2	8.1	162	116	38	16.3	44	77	176
	Winter	36	4.0	6.9	196	101	36	14.8	40	71.8	161
Bedkihal Lake	Summer	205	4.3	3.8	178	60	35	15	38	87.1	156
	Monsoon	162	4.9	3.6	158	54	31	16.6	34	86.9	149
	Winter	178	5.6	3.2	165	51	**24**	13.4	29	78.6	141

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Original Article

Advances In Graph Theorey and Its Applications

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Abstract

Mathematics plays a vital role across disciplines and graph theory is one of its most influential branches especially for structural modeling. In different fields the field of mathematics plays a key role.

In mathematics graph theory is one of the important fields used in structural models. Graph theory is a branch of mathematics that explores the properties and applications of graphs. The field graph theory began in 1736 with the Konigsberg bridge problem, making the inception of this field.

Advantages in graph theory focus on sophisticated algorithms and models for complex networks, leveraging AI/ML to tackle challenges in smart cities.

Graphs are widely used to capture relationship between entities in real applications such as social networks, road maps, The world wide web and protein interactions.

Key Words: *Graphs, Algorithms, Applications etc.*

Introduction

Graph theory is branch of mathematics that studies the relationship between nodes and edges in a collection of interconnected points called a graph. Graph help model and solve real world problems in an abstract yet initiative way, Graph theory principles are commonly used various field to research and model different applications.

In sociology for instance, graph theory is used to calculate the popularity of actors or to investigate processes of diffusion. Graph theory is a sophisticated mathematical framework for studying the characteristics and connections of graph, which are collection of nodes and edges, significance advancements have been made in graph theory and its applications in recent years.

Application in the field of computing makes extensive use of principles of graph theory. Data mining, Picture segmentation, clustering, image capture networking etc are all active areas of study in computer science.

Why Graph theory?

Graphs used to model pair wise relations between objects.
Generally, a network can be represented by a graph.
Many practical problems can be easily represented in terms of graph theory.

Historical Background

Graph theory began in 18th century, The first problem in this field that drew attention was famous seven bridges of konigsberg problem. This problem puzzled many but in 1736 a swiss mathematician named Leonhard Euler solved it. Instead of focusing on the physical feature of the city, Euler abstracted the problem to points (called vertex or nodes) and lines (called edges or links) which represented connection between the points. This idea of modeling real world problems using graphs became the foundation of model graph theory.A. F Mobius offered the concept of a total graph and a bipartisan graph in 1840 and kuratowski showed that they were planner of leisure problems.

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Current in electrical networks or circuits may be measured using the tree principle (Gustab Kirchhoff created a connected graph without cycles in 1845) and other graphical notions.

Thomas Gutherie uncovered the four-color printing error plaguing readers since 1852, In 1856 Thomas, P. kirkman and William Hamilton studied polyhedra cycles, H. Dudeney addressed a riddle problem in his 1913 talk.

In any case Sylvester proposed a graph in 1878 making connection between quantum invariants and the covariant of algebraic expression and molecular diagrams. The puzzle of the four primary colors was solved by Heinrich's computers in 1969.

Definitions

There is large number of definitions in graph theory. the following are some of the more basic ways of defining graphs and related mathematical structure.

Graph

A graph is an ordered pair G=(V,E) consisting of a non empty set V={v1,v2,v3……..} of vertices or nodes or points together with a set E={e1,e2,e3……….} of edges or arcs or lines are two element subsets of V (i.e. an edge is associated with two vertices, and that association takes the form of the unordered pair comprising those two vertices) in other words A graph G is a collection of vertices "V" and edges "E".

Key Applications of Graph Theory

Graph theory is widely used in numerous fields ranging from computer science to biology, social networks and more. Its ability to model relationship, structure and processes has made it an important tool in solving real world problems.

Any software that has to be developed any program that has to be tested in making themselves easy using graphs. Graph theory is also used in microchip designing, circuitry, scheduling problems in operating system. In general, without knowing the concept of graph we also use these in our day today life for example when we have to go to a place which is connecting with our starting point by different ways then we use the shortest road to arrive at destination soon.

Applications of graph theory in various branches of science.

In chemistry

Graph theory is used in chemistry for mathematical modeling of chemical phenomena we can make natural model of a molecule where vertices represent atoms and edges represent bond.
There is a branch of mathematical chemistry called chemical graph theory which deals with the non-trivial applications of graph theory to solve molecular problems.

In physics

The current, voltage and resistance on a circuit can be drawn by using graph theory concept.
When we want to show throw of current in circuits then we can use directed graphs. Also we can connect the different physical process with the help of graph theory concepts.

In biology

Graphs can be used in drug target identification, determining a proteins orgene's function
Graph theory can be also used in studying the structures of DNA and RNA. If we want tostudy the food chain of different animals in a ecological system, then we draw some arrow diagrams which represents the dependence of one animal upon another for their food.

In computer science

Graph theory concepts are used to develop the algorithm of different programs
Using these algorithms and programs we can solve different theoretical problems.
These are some algorithms listed below

- Shortest path algorithm in a network
- Finding minimum spanning tree
- Finding graph planarity
- Algorithms to and adjacency matrices
- Algorithms to and the connectedness.

In operational research

There are some OR problem that can be solved using graphs
In transportation problem, when we need to minimize the transportation cost or maximize the product then the graph theoretical approach is very useful.
It is also used in different assignment problems such as assigning different peoples to different jobs, manage of time table for school and colleges, assigning office stations etc.

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In Google map

Now a days, Google map is a very useful tool for travelling anywhere in the world.
Using Google map, we can find all routes from any place to any other place and also can find the shortest route.
In case of Google map, we can consider the places as vertices of graph and routes as the edges. Then the software of Google map, when find the routes between two places it finds all edges between these two places or vertices and also gives shortest edge as the shortest path.

Conclusion

The main aim of this paper is to present the importance of the graph theoretical ideas in various areas. Graphs can help solve some very complicated issues, such as lower costs, visualizations, program analysis etc. The primary objective of this paper is to highlight the significance of graph theory concepts in various domains of science subjects especially in computer applications. As an evolving field, Graph theory remains indispensable for tackling modern challenges in AI, data science.

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Original Article

Phytochemical Evaluation and Bioactive Compounds of Solanum xanthocarpum

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Abstract

Solanum xanthocarpum Schrad. & Wendl., a medicinal plant belonging to the family Solanaceae, is widely used in traditional Indian medicine for the treatment of respiratory disorders, inflammation, fever, and microbial infections. The present descriptive research study aims to evaluate the phytochemical constituents, identify major bioactive compounds through GC–MS analysis, and assess the antioxidant activity of ethanolic fruit extract of S. xanthocarpum. Qualitative and quantitative phytochemical screening revealed the presence of alkaloids, flavonoids, phenols, tannins, saponins, terpenoids, steroids, and glycosides. GC–MS analysis identified several bioactive compounds with known pharmacological activities. Antioxidant assays demonstrated significant free-radical scavenging activity, supporting the therapeutic potential of S. xanthocarpum.

Introduction

Medicinal plants are valuable sources of natural bioactive compounds used in traditional and modern healthcare systems. Phytochemicals such as alkaloids, flavonoids, phenols, and terpenoids exhibit diverse biological activities including antioxidant, antimicrobial, anti-inflammatory, and anticancer effects.

Solanum xanthocarpum, commonly known as yellow-berried nightshade or Kantakari, is an important medicinal plant used in Ayurveda, Siddha, and Unani systems of medicine. It is a key ingredient of Dashamoola formulations and is traditionally used for asthma, cough, bronchitis, fever, and urinary disorders. The present study focuses on the phytochemical evaluation, GC–MS profiling, and antioxidant potential of *S. xanthocarpum* fruit extract.

Review of Literature

Previous studies have reported that *S. xanthocarpum* contains steroidal alkaloids such as solasodine, solanine, and solasonine, which are responsible for its medicinal properties. Phytochemical screening has confirmed the presence of flavonoids, phenolic compounds, saponins, tannins, and terpenoids.

GC–MS and HPLC analyses have identified several bioactive constituents exhibiting antimicrobial, antioxidant, hepatoprotective, and anti-inflammatory activities. Ethanolic extracts have been reported to show higher phytochemical content and stronger biological activity compared to aqueous extracts.

Materials and Methodology

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1 Collection of Plant Material
Fresh fruits of *Solanum xanthocarpum* were collected from a local area Nipani and authenticated using standard floras.
2 Preparation of Extract
The fruits were washed, shade-dried, and powdered. About 50 g of powdered material was extracted with ethanol using Soxhlet extraction for 6–8 hours. The extract was filtered and concentrated.
3. Qualitative Phytochemical Analysis
Standard phytochemical tests were performed to detect alkaloids, flavonoids, phenols, tannins, saponins, terpenoids, steroids, and glycosides.
4 Quantitative Phytochemical Estimation
Total phenolic content was estimated by – Folin–Ciocalteu method, Total flavonoid content was estimated by Aluminium chloride method and Alkaloid content content was estimated by – Gravimetric method.

Results and Discussion
The present study evaluated the phytochemical composition, GC–MS profile, and antioxidant activity of ethanolic fruit extract of *Solanum xanthocarpum* to validate its medicinal potential.

Phytochemical Composition
Qualitative phytochemical screening revealed the presence of alkaloids, flavonoids, phenols, tannins, saponins, terpenoids, steroids, and glycosides in the ethanolic fruit extract of *Solanum xanthocarpum*. The detection of alkaloids is of particular importance, as the plant is known to contain steroidal alkaloids such as solasodine, which are responsible for many of its therapeutic effects (Sharma et al., 2010). The presence of flavonoids and phenolic compounds suggests strong antioxidant properties, as these compounds are efficient scavengers of free radicals.
Saponins and terpenoids identified in the extract are associated with antimicrobial and anti-inflammatory activities, while steroids and glycosides contribute to pharmacological effectiveness. These findings are in agreement with earlier phytochemical reports on *S. xanthocarpum*, confirming its rich secondary metabolite profile (Kirtikar & Basu, 2005; Singh et al., 2018).

Quantitative Phytochemical Analysis
Quantitative estimation of phytochemicals showed that total phenolic content was highest (42.7 ± 1.1 mg/g), followed by flavonoids (31.5 ± 0.8 mg/g). The high phenolic content indicates strong antioxidant potential due to the ability of phenols to neutralize reactive oxygen species. Flavonoids further enhance antioxidant and anti-inflammatory activities.
The alkaloid content was found to be 26.2 ± 0.9 mg/g, supporting the traditional use of *S. xanthocarpum* in treating respiratory disorders, infections, and inflammation. Tannins were present in moderate amounts (20.1 ± 0.6 mg/g), contributing to antimicrobial and astringent properties. These quantitative results correlate well with previously reported pharmacological activities of the plant (Harborne, 1998; Sharma et al., 2010).

GC–MS Analysis of Bioactive Compounds
GC–MS analysis of the ethanolic fruit extract identified several biologically active compounds. Solasodine, a major steroidal alkaloid detected in the extract, is well documented for its anti-inflammatory, antimicrobial, and anticancer activities (Singh et al., 2018). Fatty acids such as hexadecanoic acid and oleic acid were also identified and are known to possess antioxidant and membrane-protective effects.
Phytol and squalene, two important bioactive compounds detected through GC–MS, are reported to have strong antioxidant, anticancer, and immunomodulatory properties. The presence of these compounds confirms that *Solanum xanthocarpum* possesses a complex chemical profile, which may act synergistically to produce its therapeutic effects (Evans, 2009).

Antioxidant Activity
The antioxidant potential of *Solanum xanthocarpum* fruit extract was evaluated using DPPH and ABTS radical scavenging assays. The extract exhibited a concentration-dependent increase in percentage inhibition in both assays. At lower concentrations, moderate radical scavenging activity was observed, while higher concentrations showed significantly increased inhibition.
The ABTS assay showed slightly higher scavenging activity compared to the DPPH assay, indicating strong electron-donating capacity of the extract. This antioxidant activity can be attributed to the high content of phenolic compounds, flavonoids, and alkaloids present in the extract. Similar antioxidant behavior has been reported in earlier studies on *S. xanthocarpum* (Sharma et al., 2010; Singh et al., 2018).

Qualitative Phytochemical Screening
The qualitative phytochemical screening of the ethanolic fruit extract of *Solanum xanthocarpum* (Table.1) revealed the presence of alkaloids, flavonoids, phenols, tannins, saponins, terpenoids, steroids, and glycosides. The detection of alkaloids is particularly significant, as *S. xanthocarpum* is known to contain steroidal alkaloids such as solasodine and solasonine, which are responsible for its pharmacological properties (Sharma et al., 2010).

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The presence of flavonoids and phenolic compounds suggests strong antioxidant potential, as these compounds are effective free-radical scavengers. Saponins and terpenoids contribute to antimicrobial and anti-inflammatory activities, while steroids and glycosides enhance therapeutic efficacy. These findings are consistent with earlier reports on phytochemical constituents of *S. xanthocarpum* (Kirtikar & Basu, 2005; Singh et al., 2018).

Table 1: Qualitative phytochemical constituents of *Solanum xanthocarpum* fruit extract

Phytochemical	Observation	Result
Alkaloids	Reddish-brown precipitate	Present (+)
Flavonoids	Yellow coloration	Present (+)
Phenols	Blue-green colour	Present (+)
Tannins	Dark green colour	Present (+)
Saponins	Persistent froth	Present (+)
Terpenoids	Reddish-brown colour	Present (+)
Steroids	Green colour	Present (+)
Glycosides	Brown ring	Present (+)

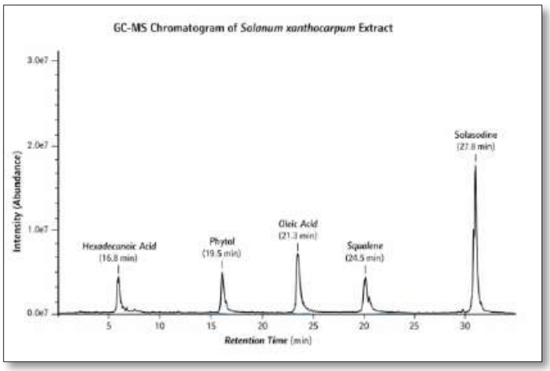
2 Quantitative Phytochemical Readings

Quantitative estimation (Table.2) revealed that the total phenolic content (42.7 ± 1.1 mg/g) was the highest among the analyzed phytochemicals, followed by flavonoids (31.5 ± 0.8 mg/g). High phenolic concentration indicates strong antioxidant activity due to their ability to donate hydrogen atoms or electrons to neutralize free radicals (Harborne, 1998).

The alkaloid content (26.2 ± 0.9 mg/g) was found to be substantial, supporting the plant's traditional use in treating respiratory disorders and infections. Tannins were present in moderate amounts (20.1 ± 0.6 mg/g), contributing to antimicrobial and astringent properties. These quantitative results confirm the medicinal importance of *S. xanthocarpum* and correlate well with previous studies (Sharma et al., 2010).

Table 2: Quantitative estimation of phytochemicals in ethanolic fruit extract

Phytochemical	Concentration (mg/g of extract)
Total Phenols	42.7 ± 1.1
Total Flavonoids	31.5 ± 0.8
Alkaloids	26.2 ± 0.9
Tannins	20.1 ± 0.6



3 GC–MS Analysis of Bioactive Compounds

GC–MS analysis of the ethanolic fruit extract (Table 3) identified several bioactive compounds with known pharmacological activities. Solasodine, a major steroidal alkaloid detected, is widely reported for its anti-inflammatory, antimicrobial, and anticancer properties (Singh et al., 2018). The presence of fatty acids such as hexadecanoic acid and oleic acid contributes to antioxidant and membrane-stabilizing effects.

Phytol and squalene, identified in the extract, are well-known natural antioxidants with reported anticancer and immunomodulatory activities. The diversity of compounds detected through GC–MS analysis indicates that *S. xanthocarpum* possesses a complex phytochemical profile, which may act synergistically to produce its therapeutic effects (Evans, 2009).

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Table 3: GC–MS identified compounds in Solanum xanthocarpum fruit extract

Peak No.	Compound Name	Molecular Formula	Retention Time (min)	Biological Activity
1	Solasodine	C27H43NO2	24.16	Anti-inflammatory, anticancer
2	Hexadecanoic acid	C16H32O2	21.42	Antioxidant
3	Oleic acid	C18H34O2	22.87	Antimicrobial
4	Phytol	C20H40O	18.61	Antioxidant
5	Squalene	C30H50	26.54	Anticancer

4. Antioxidant Assay Readings

The antioxidant activity of *Solanum xanthocarpum* (Fig.1, Table 4) fruit extract was evaluated using DPPH and ABTS radical scavenging assays. Both assays showed a concentration-dependent increase in percentage inhibition, indicating strong antioxidant potential. At higher concentrations, the extract exhibited significantly higher free-radical scavenging activity.

The ABTS assay demonstrated slightly higher inhibition values compared to DPPH, suggesting better electron-donating ability of the extract. This antioxidant activity can be attributed to the high phenolic, flavonoid, and alkaloid content present in the extract. Similar antioxidant trends have been reported earlier for *S. xanthocarpum* extracts (Singh et al., 2018; Sharma et al., 2010).

Fig 1. Antioxidant activity of *Solanum xanthocarpum* fruit extract

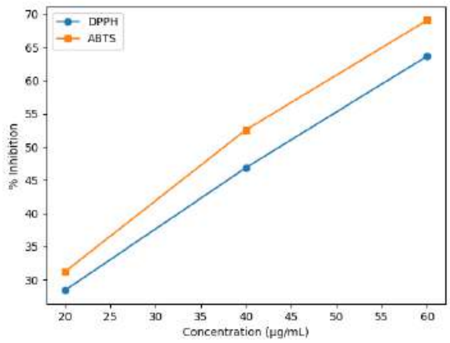

Table 4: Antioxidant activity of Solanum xanthocarpum fruit extract

Assay	Concentration (µg/mL)	% Inhibition
DPPH	20	28.4 ± 1.0
DPPH	40	46.9 ± 1.2
DPPH	60	63.7 ± 1.3
ABTS	20	31.2 ± 1.1
ABTS	40	52.6 ± 1.4
ABTS	60	69.1 ± 1.5

The extract showed dose-dependent antioxidant activity, attributed to its high phenolic and alkaloid content.

Conclusion

The present study confirms that *Solanum xanthocarpum* is a rich source of bioactive phytochemicals with significant medicinal value. The presence of steroidal alkaloids, phenols, and flavonoids contributes to its antioxidant and therapeutic properties. GC–MS analysis further validates the pharmacological potential of the plant. These findings support the traditional use of *S. xanthocarpum* and its potential application in drug development.

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Original Article

Diversity of Butterflies in Nipani and Surrounding Area, Belgaum, Karnataka

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Abstract

The butterfly diversity of the Nipani and surrounding area in Belgaum district, Karnataka, was studied in detail. Over the course of the study, various species of butterflies were identified, providing insights into the rich butterfly fauna of the region. The study highlights the key species found, their distribution, and their significance to the ecosystem. Data on species composition, seasonal variations, and habitat preferences were gathered. This research serves as a baseline for future conservation efforts and studies on the butterfly population in this region.

Key Words: *Butterfly diversity, Nipani, Belgaum, Karnataka, Lepidoptera, species composition, conservation, and habitat.*

Introduction

Butterflies are critical pollinators and serve as bioindicators, reflecting the health of the environment. The butterfly diversity in the Nipani region, located in the Belgaum district of Karnataka, has not been extensively studied. This area is characterized by a blend of forests, grasslands, and agricultural land, offering unique habitats for several butterfly species. The goal of this study was to document and analyze the butterfly species found in the region and its surroundings.

Materials and Methods

a. Study Area

The study was conducted in Nipani and its surrounding areas in the Belgaum district, Karnataka, which is part of the Western Ghats region. The area encompasses dry deciduous forests, grasslands, and agricultural landscapes, with moderate rainfall, making it an ideal habitat for a wide variety of butterfly species. The region is rich in flora, offering essential resources for butterflies in their different life stages.

Results and Discussion

During the study, total 19butterfly species were identified and they belonging to 5different families. The following table lists the common names, scientific names, and family names of the observed species:

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Sr. No.	Family	Scientific Name		Common Name	Images
1	Pieridae (2)	1	***Euremahecabe***	Common Grass Yellow	
		2	***Leptosianina***	Wandering Snowflake	
2	Nymphalidae (8)	3	***Junoniaalmana***	Peacock Pansy	 
		4	***Neptishylas***	Common Sailer	

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		5	***Melanitisleda***	Common Evening Brown	
		6	***Junonialemonias***	Lemon Pansy	
		7	***Hypolimnasbolina***	Great Eggfly	
		8	***Paranticaaglea***	Glassy Tiger	
		9	***Tirumalalimniace***	Blue Tiger	

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		10	***Euploea core***	Common Indian Crow	
3	Papilionidae (5)	11	***Graphiumagamemnon***	Tailed Green Jay	
		12	***Papiliopolymnestor***	Blue Mormon	
		13	***Papiliopolytes***	Common Mormon	
		14	***Papiliodemoleus***	Lime / Lemon butterfly	

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		15	***Pachliopta hector***	Crimson Rose	
4	Lycaenidae (3)	16	***Lampidesboeticus***	Peablue	
		17	***Tarucusnara***	Striped Pierrot	
		18	***Talicadanyseus***	Red Pierrot	
5	Hesperiidae (1)	19	***Hasorachromus***	common banded awl	

Discussion

The butterfly diversity in the Nipani region is notably high, with species from various families such as Pieridae, Nymphalidae, Papilionidae, Lycaenidae and Hesperiidae. The following points summarize the major findings of the study:

Habitat Preference: Many species in the Nymphalidae and Papilionidae families were predominantly found in mixed forest habitats, while butterflies from the Lycaenidae family were more common in grasslands and agricultural areas. Only one species found from family Hesperiidae.

Seasonal Variations: A higher diversity of butterflies was observed during the monsoon and post-monsoon periods. Species richness peaked during these seasons, likely due to the abundance of nectar-producing plants and favorable environmental conditions.

Conservation Significance: Some of the observed butterfly species play important roles in pollination, while others contribute to the food chain as prey for various predators. Their presence indicates a healthy, functioning ecosystem. However, habitat destruction, agricultural practices, and climate change pose significant threats to butterfly populations.

Conclusion

The butterfly diversity of Nipani and its surrounding area is diverse and ecologically significant. The region supports numerous species that are crucial to the ecosystem due to their role in pollination. The study highlights the importance of conserving the natural habitats in this area to maintain butterfly populations. Conservation efforts should focus on protecting these habitats from deforestation and promoting sustainable agricultural practices. Additionally, further research is needed to monitor butterfly populations and assess the impact of climate change on their distribution.

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Original Article

Study of nutritional properties of Launaea procumbens (Roxb.) a wild leafy vegetable

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Abstract

Launaea procumbens (Roxb.) Ramayya & Rajagopal is an Asteraceae plant that has traditionally been used for a variety of therapeutic purposes. It has traditionally been used to treat different kinds of diseases like dermatological problems, tumors, and diarrhea. In this present investigation a few nutritional parameters of wild green leafy vegetable belong to asteraceae Launaea Procumbens (Roxb.) Ramayya & Rajagopal has studied for its nutritional value. This plant is having good potential of phytochemicals as well as powerful ferrous, manganese potential so there is need to explore Launaea procumbens a wild vegetable for sustainable utilization.

Key words: *Launaea procumbens, Phytochemicals, minerals.*

Introduction

Launaea Procumbens

Wild edible plants are significant parts of biodiversity and their exploration has become a valuable livelihood approach and fall-back option for rural households during periods of nutritional stress (Bell J 1995, 2007). The importance of wild edible plants in food security has not been given sufficient attention (Rasingum 2012). *Launaea procumbens (Roxb.)* Ramayya & Rajagopal is an Asteraceae plant that has traditionally been used for a variety of therapeutic purposes. It has traditionally been used to treat dermatological problems, tumors, and diarrhea (Rawat *et al*., 2016). The plant's ayurvedic and herbal remedies are used to treat wounds (Wazir *et al*., 2007) The *L. procumbens* plant possesses diuretic, soporific, and tonic properties, making it a valuable source of fodder for goats.

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Moreover, the plant, with the exception of its roots, has insecticidal properties and is used to treat a variety of conditions, including inflammation, rheumatism, reproductive disorders, oxidative dysfunction in the kidney, and hormonal imbalances and liver dysfunction (Khan *et al*., 2011). Procumbent herbs; with yellow juice. Leaves in a basal rosette, repand- dentate or pinnately lobed. Heads on short breacteate penducles, solitary or clustered, along terminal, subracemose inflorescence. Involucral bracts 3 - seriate. All florets pale yellow. Achenes 4 ribbed, oblong, rugulose, black, truncate at apex. Pappus white, on white disc. Flowering and fruiting: October-February. Frequently occurs in moist And Sandy soil, cultivated fields, gardens, forest and waste places.

The main objective of the present study is to evaluate a few nutritional parameters of *Launaea Procumbens (Roxb.)* Ramayya & Rajagopal wild green leafy vegetable belongs to asteraceae consumed traditionally by the rural and tribal inhabitants of south India.

Materials And Methods

1. **Plant collection and identification**

   The plant material of *Launaea Procumbens* (Roxb) Ramayya & Rajagopal was collected from Harugeri is a town in Raibag taluka in Belgaum of the Indian state of Karnataka.
   (Harugeri- GPS N 16°31.0075' E 74 °57.1091), Species was authentically recognized and deposited at Herbarium, P. G. Department of Botany, B. K. College. To eradicate dust whole plants were washed with water and dehydrated under shade at room temperature. The dried plant sample was pulverized and kept in air tight bottle till further screening.
2. **Extraction of the plant material**

   The shade dried plant material was ground and consecutively extracted with ethanol by using Soxhlet apparatus for 6 hours at a temperature below the boiling points of the solvents. The extract was evaporated to dryness to obtain semisolid extracts.

Estimation of phytochemicals (Secondary metabolites)

A) Test for phenolic compounds (tannins, flavonoids and other phenols)

[Qualitative analysis]

Many of these compound's act as a legend for metal ions because of presence of vicinal oxygenated functions. Thus, solution of phenols produces dark green, blue or blue-black complex when mixed with ferric ions (Blois, 1958; Harbone, 1973)

B) Estimation of total phenolic content (TPC) [Quantitative analysis]

The total phenolic content was estimated by the standardized method of Bray and Thorpe (1954) carried out with Folin–Ciocalteu reagent (FCR) (Bray and Thorpe, 1954).
A calibration curve was done for standard phenol (gallic acid) using different concentration (R2 =0.979) (Fig. 1). The total phenolic content was expressed in mg of gallic acid equivalents (GAE)/g dry weight (DW) of extract (Rao *et al*., 2011).

A) Test for flavonoid (TFC) (Qualitative)

Shinoda test: Some pieces of magnesium ribbon was added to the test solution and highly concentrated HCl added to this. After few minutes pink scarlet, crimson red otherwise green to blue colour was formed (Vimalkumar *et al.*, 2014).

B) Estimation of total flavonoid content (TFC) (Quantitative)

Total flavonoid estimation was carried out by the aluminium chloride colorimetric method (Chang *et al.*, 2012). A calibration curve was done for standard flavonoids (rutin) using different concentration (R^2 = 0.978) (Fig. 1). The total flavonoid content was calculated as mean ± SD (n=3) and expressed as mg/g of rutin equivalents (RE) DW of dry weight extract (DW) (Suhad and Viorica, 2008).

A) Test for tannins (Qualitative)

Alkaline reagent test: 2 ml of test sample was mixed with 2ml of NaOH solution, yellow to red precipitate was observed. (Vimalkumar *et al.*, 2014).

B) Determination of tannins (Quantitative)

Tannin was quantified by the method of Trease and Evans (1978). The standard calibration curve was obtained by tannic acid. (Ram and Mehrotra, 1993; Sane, 2002).

A) Test for alkaloids (Qualitative)

Tannic acid test: 2 ml of 10% tannic acid solution was mixed with 2 ml of test sample, buff coloured precipitate was observed (Neelapu *et al.*, 2011).

B) Determination of alkaloids (Quantitative)

The alkaloid was estimated by the method of Harbone (1973).
The amount of alkaloid was determined using the following formula.

% Alkaloid = Final weight of sample/Initial weight of extract × 100

A) Estimation of Ascorbic acid

The ascorbic acid was estimated by the volumetric method of Sadasivam and Theymoli (1987).

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CALCULATION:

Amount of Ascorbic acid (mg/100gm sample)

=0.5mg/V1 ml ×V2/15 ml× 100ml / weight of the sample × 100

A) Estimation of Protein

Estimation of protein has followed by Lowry's method. (1951) The standard calibration curve was obtained by Bovin serum albumin.

Mineral Analysis

Mineral analysis was carried out from Kasturi Agrotech, department of Biotechnology Smt. Kasturbai Walchand College, Sangali.

Sample preparation – 1 gm sample used for acid digestion (20-25 ml) and final volume made upto 100 ml with distilled water. Na, K, Ca, in plant sample was analyzed by Flame photometer (Thermofisher FP114) and Fe, Mn, Zn and Cu in plant sample was analyzed using atomic absorption spectrophotometer (Thermofisher AA203).

Results And Discussion:

1 Estimation of phytochemicals (Secondary metabolites)

Secondary metabolites that present in plants are associated with the healing properties of plants. To know the status of these secondary metabolites in *Launaea Procumbens* plant species, the plant species was analyzed for their total phenols and flavonoids.

1.a. Total phenolic and flavonoid content

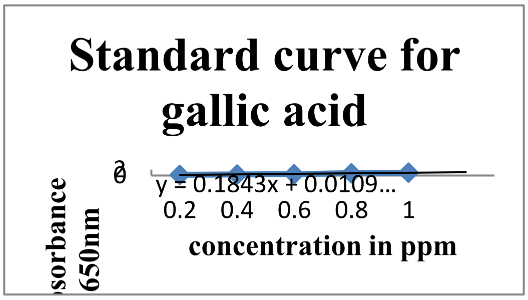

Fig. 1: Standard curve of phenols (gallic acid)

During present investigation *Launaea Procumbens* a wild vegetable was analyzed for their secondary metabolites especially for phenols and flavonoids. Results are tabulated in Table 1. Standard curve of phenols represented in Fig. 1. The selected plant species was tested for their secondary metabolites by using ethanol solvent extract. The results showed that the TPC in the ethanolic extracts was 419.89 ± 0.5 mg GAE /100g DW.

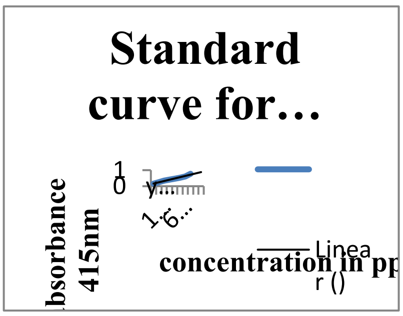

Fig. 2: Standard curve of flavonoids (Rutin)

Flavonoids shows anti-inflammatory, antimicrobial, antioxidant and anticancer activities (Tapas et al., 2008). Therefore, to know the amount of flavonoids in selected plant species it was screened for their flavonoid content by using ethanol solvent. The results acquired in the present investigation for quantitative estimation of flavonoids are represented in Table 1.

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Standard curve for flavonoids is also represented in Fig. 2. In *Launaea Procumbens* it was (244.00 ± 0.4) in ethanol extract.

1.b. Tannin content of selected plant species:

In plants tannins may help to regulate the growth of tissues. They are also found in the heartwood of conifers and play a role in inhibiting microbial activity, thus resulting in the natural durability of the wood. In present piece of work the tannin content of the plant extract was evaluated by the linear regression equation obtained from the standard graph (Fig.3).

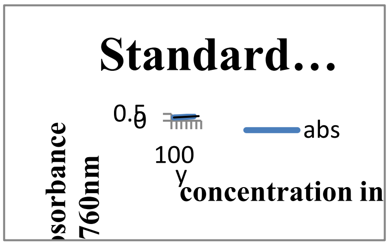

Fig.3: Standard curve of tannin

(Tannic acid)

The obtained results are presented in (Table-1). It was found that content of tannin was present in *Launaea procumbens* (205± 0.09).

1.c. Alkaloid content

Alkaloids are one of the earliest isolated bioactive compounds from plants and have heterocyclic nitrogen compounds. Basically, alkaloids derived from amino acids and the nitrogen present in it that gives them alkaline properties (Kovacevic, 2004).

To know the status of alkaloids in selected species *Launaea procumbens* was studied for quantification of alkaloids. The obtained results are shown in Table 6. It was found that alkaloids were present in *Launaea procumbens* (11.0 ± 0.43%). Due to the presence of alkaloids both the species showed positive results towards the antimicrobial activities.

1. d. Protein content

Sudipta Sarkar et al. (2020), studied protein estimation by Lowrys method. Estimation of total protein content by Lowry's method is the most widely accepted procedure when it comes to determine the amount of protein present in any biological sample, they reported in *Enhydra fluctuans* has been found 48.79±1.84 mg BSAE/g of FW.

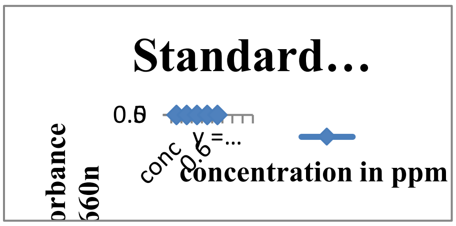

Fig.4: Standard curve of Protein

(Bovin serum

In present work the protien content of the plant extract was evaluated by the linear regression equation obtained from the standard graph (Fig.4). The obtained results are presented in (Table-1). It was found that content of protein was present in *Launaea procumbens* (81 ± 0.09).

1. e. Ascorbic acid content

Many species of the Asteraceae can be included in a regular, healthy diet. *Cichorium intybus*, or chicory, contains 22.15 mg of vitamin C per 100 g of dry matter and more than 60% of its total organic acid content is malic acid. (Jafarinia and Jafarinia, 2019; Sánchez-Mata, 2012; Nwafor, 2017) It was found that the present analysis the ascorbic acid content 142.00 ± 0.3: mg/100gm sample.

Table 1: Phytochemicals estimation of *Launaea Procumbens* (n=3)

Sl. No.	Phytochemical	Values Obtained
1	Total phenolic content	419.89 ± 0.5
2	Total flavonoid content	244.00 ± 0.4
3	Tannins	205.00 ± 0.09
4	Alkaloids	11.00 ± 0.43%
5	Protein	81.00 ± 0.09
6	Vitamin C (Ascorbic acid)	142.00 ± 0.3

Measurements are mean ± SD.
Total phenols: mg of GAE/100g of DW; Total flavonoids: mg of RE/100g of DW;
Tannins: mg of TA/ 100g of DW: Protein: µg of BSA/ g of DW
Ascorbic acid: mg/100gm sample

2 Mineral analysis

Minerals are essential for human nutrition and that are collected by consumining different plants where they get accumulated maximumly (Ajasa *et al*., 2004). Various inorganic constituents like Na+, K+, Fe3+, Mn2+, Ca2+, Cu2+, Zn2+ were estimated from the leaves of compositae member plant species *Launaea procumbens.* To know the status of minerals in ***Launaea Procumbens*** was studied for analysis of minerals. The obtained results are shown in Table 2.

Table 2: Mineral analysis of *Launaea Procumbens*

Sl No.	Parameters	Values obtained
1	Sodium (%)	0.96%
2	Potassium (%)	0.55%
3	Calcium (%)	0.48%
4	Zinc (ppm)	62.36
5	Ferrous (ppm)	843.12
6	Copper (ppm)	5.56
7	Magnese (ppm)	241.36

For good health, a balance is necessary in potassium and sodium contents. In the present investigation the plant *Launaea procumbens* good amount of potassium and sodium contents was observed. It was found that Sodium content (0.96%) was found to be higher than that of potassium (0.55%). The calcium content was also observed in *Launaea procumbens* it was 0.48%.

In micronutrient zinc, ferrous, copper, magnese has analysed from *Launaea procumbens. Among* the four nutrients ferrous was found more abundantly that is 843.12 ppm. Therefore, the species has medicinal potential against iron deficiency problems like Sickle cell anemia. Next to ferrous magnese was also found in good amount. The results are depicted in the table 2. low concentrations of Copper and Zinc were observed in *Launaea procumbens.*

Conclusion:

It can be concluded from result that studied species *Launaea procumbens* having good potential of phytochemicals as well as powerful ferrous, manganese potential. It indicates that the species have highest level of iron shows their high medicinal potential properties against iron deficiency diseases. So there is need to explore *Launaea procumbens* a wild vegetable for the sustainable utilization.

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Original Article

Magnetohydrodynamic Couple stress nanofluid flow with melting heat transfer, second order slip, with radiation and chemical reaction Effects over a Nonlinear Stretching Sheet: A Numerical Study

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Abstract
This study presents a comprehensive numerical investigation of magnetohydrodynamic (MHD) couple stress nanofluid flow over a nonlinear stretching sheet, incorporating second-order velocity slip, melting heat transfer, nonlinear thermal radiation, and chemical reaction effects. The governing boundary layer equations representing mass, momentum, energy, and concentration conservation are formulated under the assumptions of steady, two-dimensional flow. The couple stress model accounts for microstructural fluid behaviour, while the inclusion of second-order slip conditions offers a more accurate representation of microscale and nanoscale transport phenomena. Melting at the sheet surface introduces additional complexity in the energy balance, relevant to applications such as latent heat thermal storage and phase-change materials. Nonlinear radiation effects are incorporated using the Rosseland approximation, providing realistic modelling of high-temperature environments. Chemical reaction effects are considered to simulate reactive species transport in biomedical and catalytic processes. The transformed nonlinear ordinary differential equations are solved using matlab BVP4c with a shooting technique. The effects of key physical parameters on velocity, temperature, and concentration distributions are analysed and graphically presented. Results demonstrate that increasing the magnetic field strength and couple stress parameter significantly alters flow characteristics and heat transfer rates. The inclusion of second-order slip reduces shear stress at the boundary, while melting enhances thermal transport near the sheet. This multifactorial model is anticipated to provide valuable insights for advanced applications in microfluidic devices, biomedical engineering, and heat transfer augmentation systems.
Keywords: *MHD, couple stress fluid, chemical reaction, melting heat transfer, nonlinear thermal radiation, nonlinear stretching sheet,*

Introduction

The study of magnetohydrodynamic (MHD) flows has garnered significant attention due to its diverse applications in engineering and biomedical fields, such as in cooling systems, drug delivery, and tissue engineering. These applications often involve complex fluid behaviors that necessitate advanced modeling techniques. In this context, the combination of MHD effects, couple stress fluids, nanofluids, and various thermal and chemical phenomena presents a rich area of research. Jafarunnisa [1] explores the transient MHD flow behavior of a nanofluid over a permeable, stretching surface within a porous medium, incorporating the influences of nonlinear thermal radiation, velocity slip, surface mass flux, and convective heat exchange. T. Maranna et Al. [2] analytically examines the effects of MHD and thermal radiation on the steady flow of an incompressible, non-Newtonian nanofluid over a permeable stretching/shrinking surface, incorporating Navier's slip conditions and mass transpiration. The analysis considers blood-based nanofluids containing silver and copper nanoparticles, highlighting their distinct thermal and flow behaviors under heat exposure.

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Faizal et al. [3] investigates the heat transfer characteristics of a micropolar hybrid nanofluid flow over a stretching sheet, considering the effects of velocity and thermal slip conditions, non-uniform heat generation/absorption, thermal radiation, and magnetohydrodynamics. Dharmendar Reddy et al. [4] examines the influence of thermal radiation and viscous dissipation on MHD flow of Fe_3O_4–ethylene glycol nanofluid over a shrinking sheet, considering heat generation/absorption and velocity slip effects.

Nanofluids, composed of nanoparticles dispersed in conventional base fluids, offer superior thermal characteristics, making them suitable for advanced heat transfer applications. The addition of nanoparticles such as copper (Cu) and aluminum oxide (Al_2O_3) significantly enhances thermal conductivity and heat transfer efficiency. However, modeling these fluids becomes more intricate when accounting for non-Newtonian properties, particularly in couple stress fluids is accounted by Zhu et al. [5]. Couple stress fluids consider micro-rotational motions and extra stress terms, making them especially applicable to microscale and biomedical flow scenarios. Integrating couple stress theories into nanofluid analysis enables a more precise depiction of fluid behavior in these specialized environments. The concept of couple stress fluids was originally introduced by Stokes. [6]. Research on this phenomenon has a wide range of applications, including lubrication systems, blood circulation, and biorheological fluid dynamics. [7], [8], [9]. [10]. Roja et al. explores the effects of Hall and ion phenomena on the flow of a couple stress nanofluid within an inclined channel, incorporating convective heat transfer, internal heat generation, velocity slip and thermal radiation. Kathyayani et al. [11] investigates how thermal radiation, viscous dissipation, and Joule heating affect entropy generation and the flow behavior of a Maxwell hybrid nanofluid over an exponentially stretching surface, taking into account couple stress effects. Similar effects on the electroosmotic flow of a couple stress nanofluid composed of blood and gold nanoparticles is proposed by Sridhar et al. [12], Rajamani et al. [13].

Melting heat transfer is an important research area with diverse applications across modern technologies. It plays a key role in processes such as welding, crystal growth, thermal insulation systems, energy storage, additive manufacturing, electronics cooling, permafrost thawing, semiconductor fabrication and metal casting. Khan et al. [14] examines the behavior of mass transfer and melting heat in the stagnation point flow of generalized Burgers fluid over a stretching surface while taking into account nonlinear thermal radiation. Kayalvizhi, J. and Vijaya Kumar together [15] studied entropy analysis of stagnation point flow of EMHD hybrid nanofluid across a porous stretching sheet with melting heat transfer when thermal radiation is present. Impact of Thermal Radiation, Inclined Magnetic Field, and Melting Heat Transfer on Williamson Nanofluid above a Stretching Sheet is investigated by Srinu et al. [16]. Krishnamurthy et al. [17]examined the effects of thermal radiation and chemical reactions on MHD boundary layer flow with velocity slip and melting heat transfer of a nanofluid induced by a nonlinear stretching sheet. Ilango et al. [18] aims to investigate the melting heat transfer of Casson nanofluid flow in magnetohydrodynamics on a porous stretching sheet with radiation, full slip, and viscous dissipation effects. The effect of MHD melting heat transfer with thermal radiation and slip effect over Micropolar fluid past a stretching Sheet is explored by [19], [20]. Magnetohydrodynamic melting heat transfer in presence of thermal radiation and various effects are investigated by [21], [22], [23], [24].

The impact of melting and slippage on mixed convective heat transport across porous microchannels with electrically conducting and non-conducting walls comprising fluid injection and ejection flow mechanics in a microchannel with a transverse magnetic field is developed by Akinshilo et al. [25]. A computational study has been conducted by Reddy et al. [26] on the steady laminar incompressible viscous magneto hydrodynamic boundary layer flow of an Eyring-Powell fluid across a nonlinear stretching flat surface in a nanofluid with slip condition and heat transfer via melting effect. Later Mabood et al. [27] investigated numerically the couple stress nanofluid flow across a stretching sheet with melting and nonlinear radiation in magnetohydrodynamics. Further with first-order slip, the second law of thermodynamics is also included with Brownian moments and nanofluid properties for thermophoresis are encountered. Ashok et al. [28] focuses their research on Impact of nonlinear thermal radiation on Jeffrey nanofluid heat transfer and second order slip flow across a stretching sheet with an uneven heat source/sink. Mabood et al. [29] examines MHD flow and melting heat transfer of a nanofluid across a stretching surface while accounting for thermal radiation and a second-order slip model.

Chemical reactions are classified as heterogeneous or homogeneous based on whether they occur at interfaces or within a single phase. Studying heat transfer in nanofluids with chemical reactions and thermal radiation is crucial due to its widespread applications in engineering and science. Abbas et al. [30] numerically analysed the flow of a non-Newtonian tangent hyperbolic nanofluid across a nonlinearly stretched surface while accounting for a chemical reaction mechanism, thermal radiation, and a prescribed surface temperature. Maheshkumar et al. [31] examines Chemical Reaction's Effect on MHD Boundary Layer Nanofluid Flow via a Nonlinear Stretching Sheet Using the Haar Wavelet Collocation Method with Thermal Radiation. Satya Narayana et al. [32] investigated the impact of the heat source on the 3D chemically reacting couple stress nanofluid flow caused by the stretching surface. Bioconvection in Couple Stress Hybrid Nanofluid Incompressible Flow for Targeted Drug Delivery via Porous Stretching Sheet Using Magnetic Nanoparticles and Chemical Reaction is explored by Alharbi et al. [33].

Many earlier studies have focused on simplified scenarios—such as basic slip flow, linear thermal radiation, linear stretching sheets, or Newtonian fluids—often considering only a few effects in isolation or limited combinations. In

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contrast, this work offers a novel and comprehensive numerical investigation of magnetohydrodynamic (MHD) couple stress nanofluid flow, incorporating second-order slip, chemical reactions, melting heat transfer, and nonlinear thermal radiation over a nonlinear stretching sheet. Such an integrated analysis is scarcely found in the existing literature and provides a more realistic representation of conditions encountered in advanced industrial and biomedical systems. Practical applications include microfluidic cooling, enhanced oil recovery, polymer extrusion, and biomedical processes where precise control of heat and mass transfer in non-Newtonian nanofluids is essential. Furthermore, this study lays the groundwork for future extensions involving unsteady and three-dimensional flows, variable magnetic fields, and bio-reactive or convective effects.

Mathematical formulation

We consider a steady, two-dimensional, laminar boundary layer flow of an incompressible couple stress nanofluid over a nonlinear stretching sheet in the presence of a uniform magnetic field. The surface is assumed to be melting, and the effects of nonlinear thermal radiation, second-order velocity slip, and chemical reaction are incorporated into the model. The stretching velocity of the surface is taken as $u_w(x) = ax^n$, where a> 0 is the stretching constant and $n > 0$ determines the degree of nonlinearity. Let x be the coordinate along the sheet and y the coordinate normal to it. The corresponding velocity components in the x and y directions are denoted by u and v respectively. The temperature and nanoparticle concentration of the nanofluid are represented by T and C. A uniform magnetic field B_0 is applied perpendicular to the sheet.

The wall temperature T_w and nanoparticle concentration C_w are assumed to be constant at the stretching surface. As $y \to \infty$ the fluid approaches its ambient temperature $T \to \infty$ and ambient nanoparticle concentration $c \to \infty$ .The temperature of the melting surface is denoted by T_m, while the ambient (free-stream) temperature is T_∞, with the condition $T_\infty > T_m$. It is important to note that the stretching surface is maintained at a temperature T_m and nanoparticle concentration C_w, both of which are higher than their respective ambient values, i.e. T_∞ and C_∞ respectively. The coordinate system and the corresponding physical flow model are illustrated in **Figure 1**. Based on the defined setup, the governing equations for momentum, energy, and nanoparticle concentration are formulated as follows [17],[29]

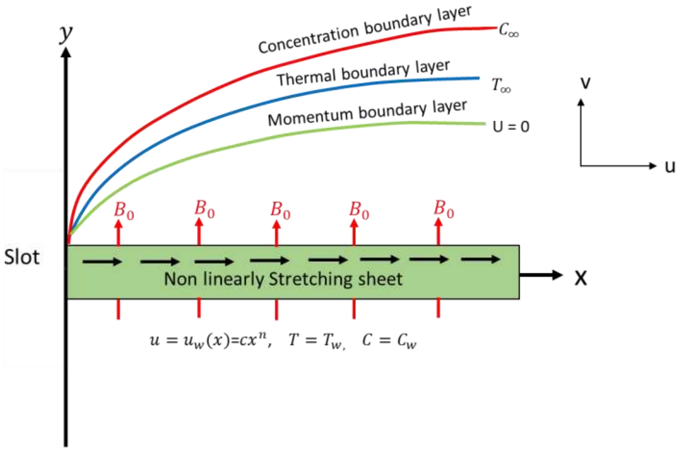

Figure 1. Physical model of the problem

$u_x + v_y = 0$ (1)

$uu_x + vu_y = \vartheta u_{yy} - \frac{\eta_0}{\rho} u_{yyyy} - \frac{\sigma {B_0}^2 u}{\rho}$ (2)

$uT_x + vT_y = \alpha T_{yy} - \frac{1}{\rho c_p}\frac{\partial q_r}{\partial y} + \tau\left[D_m C_y T_y + \frac{DT}{T_\infty}\left(T_y\right)^2\right]$ (3)

In contrast to the commonly used linearized Rosseland approximation, this study employs the **nonlinear Rosseland diffusion approximation**, which remains valid for both small and large temperature differences between the wall temperature T_w and the ambient temperature T_∞ According to Rosseland, the radiative heat flux is expressed as:

$q_r = \frac{-4\sigma^*}{3k^*}\frac{\partial T^4}{\partial y}$

here, qr is the radiative heat flux, σ∗ is Stefan Boltzmann constant, k∗ is the absopration coefficient. The temperature variations within the flow are assumed to be sufficiently small, allowing the term T^4 to be approximated as a linear function of the temperature T. By expanding T^4 in a Taylor series about the free stream temperature T_∞ and neglecting higher order terms, we obtain the linearized form as$T^4 \approx 4T{T_\infty}^3 - 3{T_\infty}^3$ (4)

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Combining equation (3) and (4) we obtain

$$uT_x + vT_y = \alpha T_{yy} + \frac{16\sigma^*}{3\rho C_p k_*} T^3 T_{yy} + \tau\left[D_m C_y T_y + \frac{DT}{T_\infty}\left(T_y\right)^2\right] \quad (5)$$

$$uC_x + vC_y = D_m C_{yy} + \frac{DT}{T_\infty} T_{yy} - K_r(C - C_\infty) \quad (6)$$

The associated boundary conditions are

$$u = u_w + \delta_1 u_y + \delta_2 u_{yy},\ \ u_{yy} = 0\ ,\ T = T_m\ ,\ C = C_w \ \text{ at } y = 0$$

$$u \to 0,\ u_y = 0,\ T \to T_\infty,\ C \to C_\infty,\ as\ y \to \infty \quad (7)$$

$$k\left(T_y\right)_{y=0} = \rho\left(\lambda + C_s(T_m - T_0)\right)v(x,0), \quad (8)$$

The velocity components in the x and y directions are denoted by u and v, respectively. The parameters used in the model include: α for thermal diffusivity, υ for kinematic viscosity, σ for electrical conductivity, and ρ_f for the density of the base fluid. Other physical constants are D(mass diffusion coefficient), D_T (thermophoresis diffusion coefficient), D_B (Brownian diffusion coefficient), and τ represents the ratio of nanoparticle heat capacity to base fluid heat capacity. The parameter ccc is the volumetric expansion coefficient, ρ_p nanoparticles density, C is the dimensionless nanoparticle volume fraction, and $C_p$is the specific heat at constant pressure.

The velocity slip condition (for arbitrary Knudsen numbers), Kn is defined as [34]

$$u_{slip} = \frac{2}{3}\left(\frac{3-\alpha_1 l^3}{\alpha_1} - \frac{3(1-l^2)}{2K_n}\right)\lambda u_y - \frac{1}{4}\left(l^4 + \frac{2}{{K_u}^2}(1-l^2)\lambda^2 u_{yy} = Au_y + Bu_{yy}\right) \quad (9)$$

where l=min (1/Kn, 1), $0 \le \alpha \le 1$, where α = momentum accommodation coefficient and λ is the molecular mean free path. $A = \frac{2}{3}\lambda\left(\frac{3-\alpha_1 l^3}{\alpha_1} - \frac{3(1-l^2)}{2K_n}\right)$ and $B = -\frac{1}{4}\lambda^2\left(l^4 + \frac{2}{{K_u}^2}(1-l^2)\right)$, $A > 0$, and $B < 0$ are constants. $K_n = \frac{\lambda}{l}$, Knudsen number

Introducing the following similarity transformations [17], [35]

$$\eta = y\sqrt{\frac{a(n+1)}{2\vartheta}}\, x^{\frac{n-1}{2}},\ u = ax^n f'(\eta),\ v = -\sqrt{\frac{a\vartheta(n+1)}{2}}\, x^{\frac{n-1}{2}}\left[f(\eta) + \frac{n-1}{n+1}\eta f'(\eta)\right]$$

$$\theta(\eta) = \frac{T-T_m}{T_\infty - T_m}\ ,\ \phi(\eta) = \frac{C-C_w}{C_\infty - C_w} \quad (10)$$

Using $T = T_\infty[1 + (\theta_w - 1)\theta]$, where $\theta_w = \frac{T_m}{T_\infty}$,

Applying similarity transformations (10) to equations (2), (5) and (6), The reduced dimensionless equations are as follows.

$$f^4 - S1f^3 - f'^2 + ff'' - Mf' = 0 \quad (11)$$

$$\frac{1}{\Pr}\theta'' + Rd(1 + (\theta_w - 1)\theta)^3\theta'' + Nt\theta'\phi' + Df\theta'^2 + f\theta' = 0 \quad (12)$$

$$\phi'' + Scf\phi' + Nt\theta'' - \gamma\emptyset = 0$$

The transformed boundary conditions are

$$Me\theta'(0) + Prf(0) = 0,\ \ f'(0) = 1 + \delta_1 f''(0) + \delta_2 f'''(0), \theta(0) = 0, \emptyset(0) = 0 \ \text{ at } \eta = 0,$$

$$f'(\infty) = 0, f''(\infty) = 0,\ \ \theta(\infty) = 1, \emptyset(\infty) \to 1 \ \text{ as } \eta \to \infty$$

The physical parameters present in this study are

$$p_r = \frac{\vartheta}{\alpha},\ \ Sc = \frac{\vartheta}{D_m},\ \ Nt = \frac{\tau D_m(C_\infty - C_w)}{\vartheta},\ \ Df = \frac{\tau D_T T_\infty}{\vartheta(T_\infty - T_m)},\ \ Rd = \frac{16\sigma^* {T_\infty}^3}{3\rho C_p k_*},\ \ M = \frac{\sigma {B_0}^2}{\rho a},\ \ Me = \frac{C_f(T_\infty - T_m)}{\lambda + C_s(T_m - T_0)},\ \ S1 = \frac{a(n+1)^2\eta_0}{2\vartheta^2\rho},\ \ \gamma_r = \frac{K_r}{a} \quad (13)$$

The melting parameter, denoted as Me, is determined by a composite of the Stefan numbers for the fluid and solid phases, represented by $C_f(T_\infty - T_m)/\lambda$ and $C_s(T_m - T_0)/\lambda$ respectively.

Physical quantities

The local skin friction coefficient: Surface drag force C_{fx} is defined as

$$C_{fx} = \frac{\tau_w}{\rho {u_w}^2}, \quad (14)$$

where τ_w represent shear stress at the surface can be given as

$$\tau_w = \mu\left(\frac{\partial u}{\partial y}\right)_{y=0} - \frac{\eta_0}{\rho}\left(\frac{\partial^3 u}{\partial y^3}\right)_{y=0} \quad (15)$$

The non-dimensional form is

$$(Re_x)^{1/2} C_{fx} = \frac{2}{\sqrt{2(n+1)}}\left(f''(0) - S1f'^{v}(0)\right) \quad (16)$$

Where $(Re_x)^{1/2}$denotes the Local Reynolds number.

Heat transfer rate: The local temperature gradient or Nusselt number Nu_x can be defined as

$$Nu_x = \frac{xq_w}{k(T_\infty - T_m)} \quad (17)$$

where q_w represent heat flux at the surface can be given as,

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$q_w = -k(1 + \frac{16\sigma^*}{3k_1 k} T^3 \left(\frac{\partial T}{\partial y}\right)_{y=0}$ (18)

The non-dimensional form is

$(Re_x)^{-1/2} Nu_x = -\sqrt{\frac{2}{n+1}} \frac{1}{(\theta_w - 1)} \theta'(0)$ (19)

Mass transfer rate: The local Sherwood number Sh_x can be defined as

$Sh_x = \frac{x q_m}{D_m (C_w - C_\infty)}$ (20)

where q_m represent mass flux at the surface can be given as,

$q_m = -D_m \left(\frac{\partial C}{\partial y}\right)_{y=0}$ (21)

The non-dimensional form is $(Re_x)^{-1/2} Sh_x = -\sqrt{\frac{2}{n+1}} \emptyset'(0)$(22)

where $Re_x = \frac{u_w(x)}{\vartheta}$, is the local Reynolds number.

Results and Discussion

In this study, we have investigated the Magnetohydrodynamic (MHD) couple stress nanofluid flow over a nonlinear stretching sheet incorporating second-order velocity slip, melting heat transfer, nonlinear thermal radiation, thermophoresis, and chemical reaction effects. The governing dimensional boundary layer equations for momentum, energy, and concentration were formulated by considering the effects of couple stresses, magnetic field, and nanoparticle dynamics.

By employing appropriate similarity transformations, the complex partial differential equations were reduced to a set of coupled nonlinear ordinary differential equations. These equations were parameterized using key nondimensional physical parameters including the magnetic parameter M, couple stress parameter S1, Prandtl number Pr, Schmidt number Sc, thermophoresis parameter Ntt, nonlinear thermal diffusion parameter Df, radiation parameter Rd, melting parameter Me, and the chemical reaction rate parameter Υ_r. The second-order velocity slip was modeled through parameters δ1 and δ2. An efficient Numerical scheme Matlab BVP4c shooting technique is employed to solve these ODEs and the effects of these parameters are discussed through graphs.

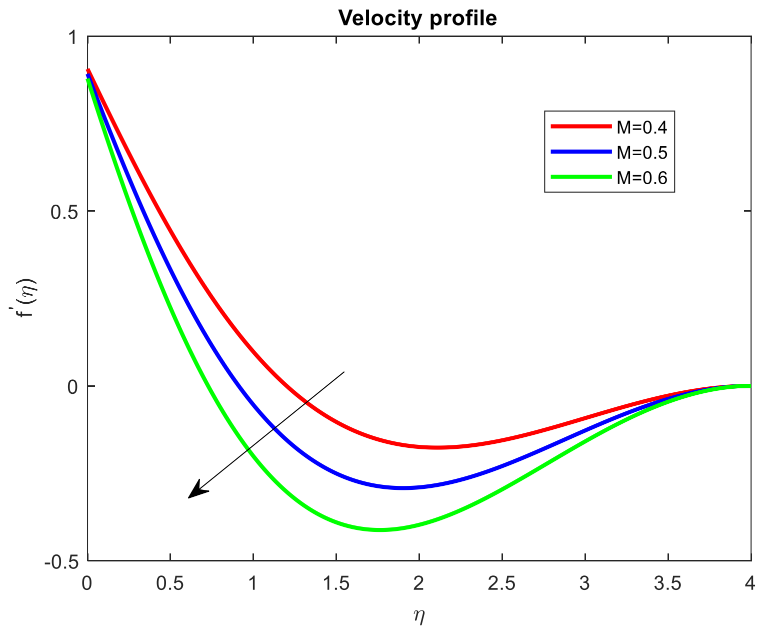

Fig 2(a). Variation of magnetic parameter on velocity profile

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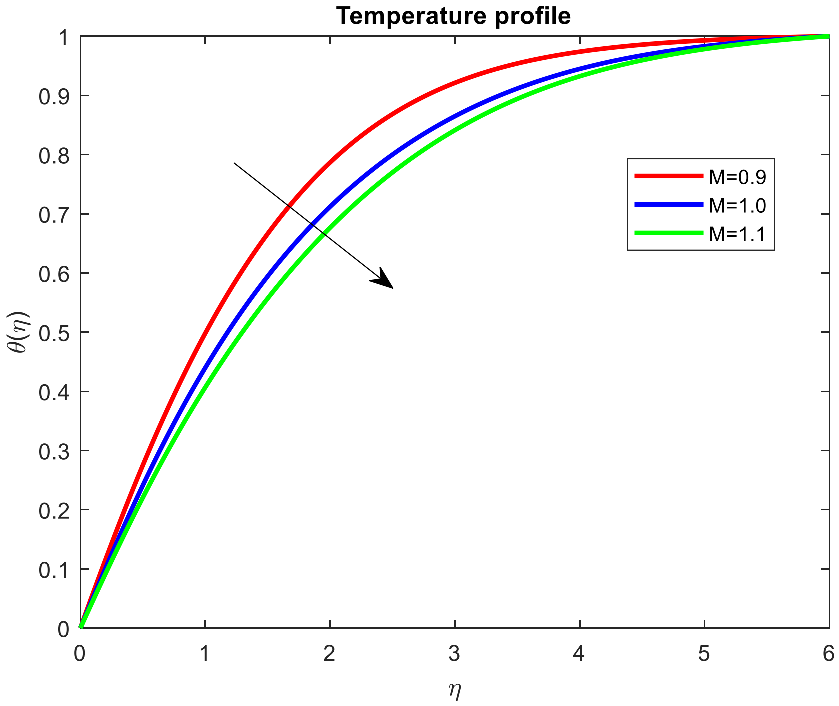

Fig 2(b). Variation of magnetic parameter on Temperature profile

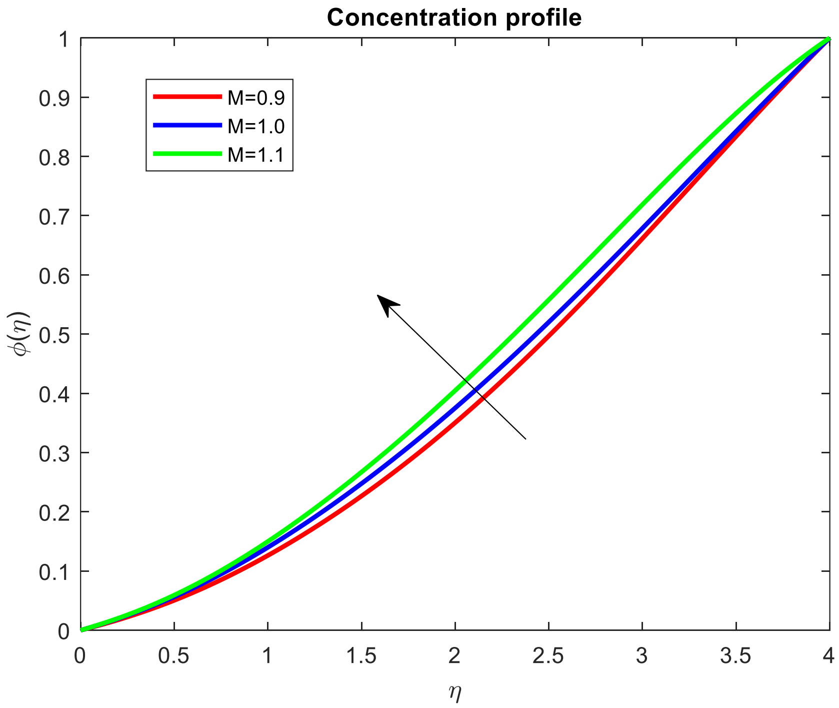

Fig 2(c). Variation of magnetic parameter on Concentration profile

The influence of the magnetic parameter M is prominently observed in the velocity, temperature, and concentration profiles, as illustrated in figures 2(a)-2(c). An increase in M leads to a substantial reduction in the fluid velocity due to the action of the Lorentz force, which opposes the motion of the electrically conducting nanofluid. This magnetic resistance inhibits the momentum transfer, resulting in a thinner velocity boundary layer. Consequently, the reduced convective transport of heat causes a rise in the temperature distribution near the surface, thereby thickening the thermal boundary layer. Additionally, the decreased fluid motion weakens the advective mass transfer, allowing nanoparticles to remain closer to the wall, which slightly enhances the concentration profile.

The couple stress parameter significantly influences the flow, thermal, and concentration fields as depicted in fig 2(a)-2(c). As this parameter increases, it introduces stronger microstructural effects within the fluid, representing the internal resistance due to couple stresses. This additional resistance impedes the motion of fluid layers, leading to a

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reduction in the velocity profile and a thinner momentum boundary layer. The increased internal friction enhances viscous dissipation, which contributes to a rise in the temperature profile, thereby thickening the thermal boundary layer. Furthermore, the suppressed fluid motion diminishes the rate of convective mass transport, causing nanoparticles to accumulate closer to the surface and thus slightly increasing the concentration profile.

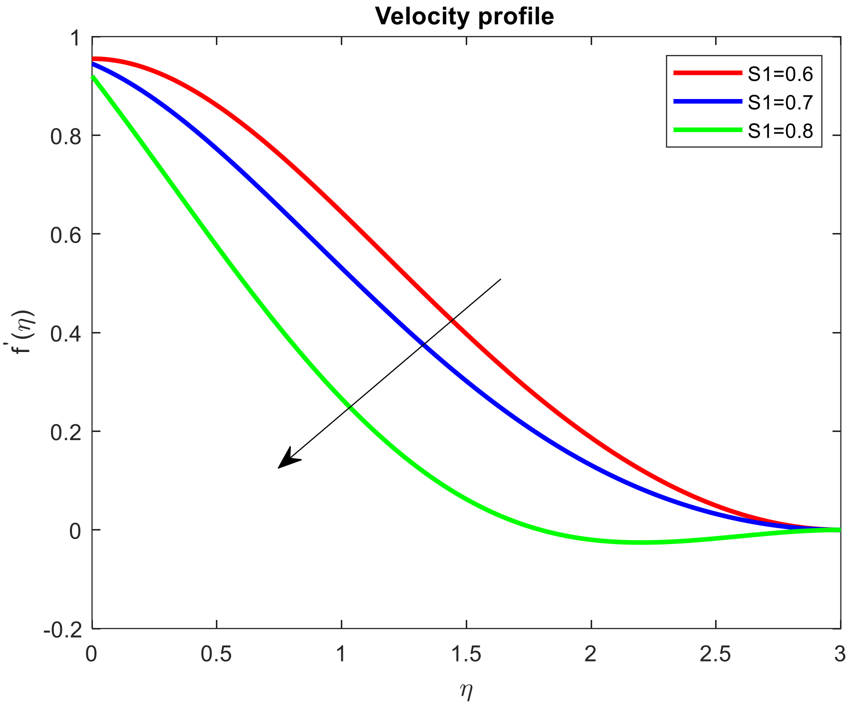

Fig 3(a). Variation of Couple stress parameter on velocity profile

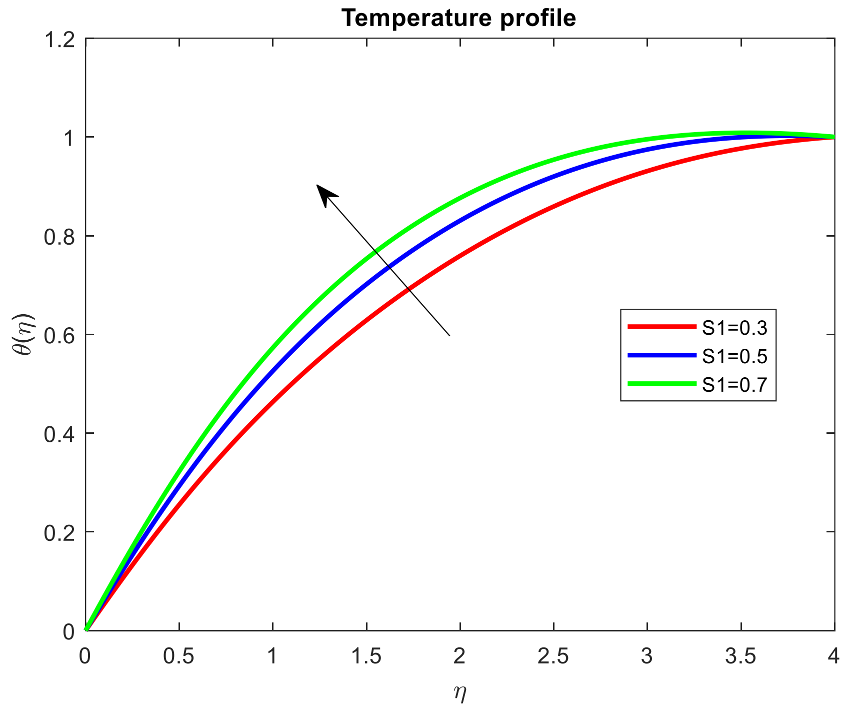

Fig 3(b). Variation of Couple stress parameter on velocity profile

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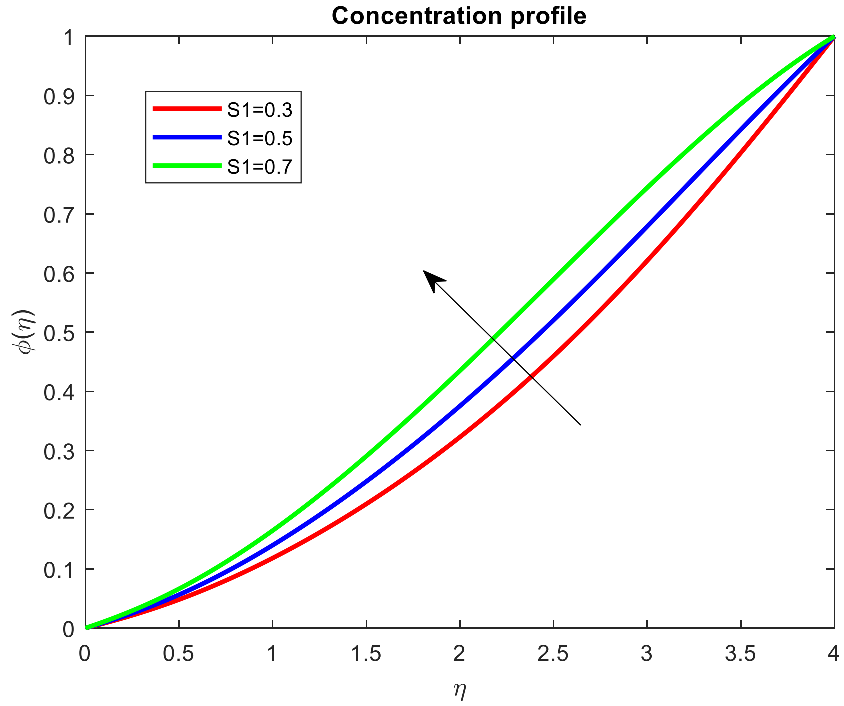

Fig 3(c). Variation of Couple stress parameter on velocity profile

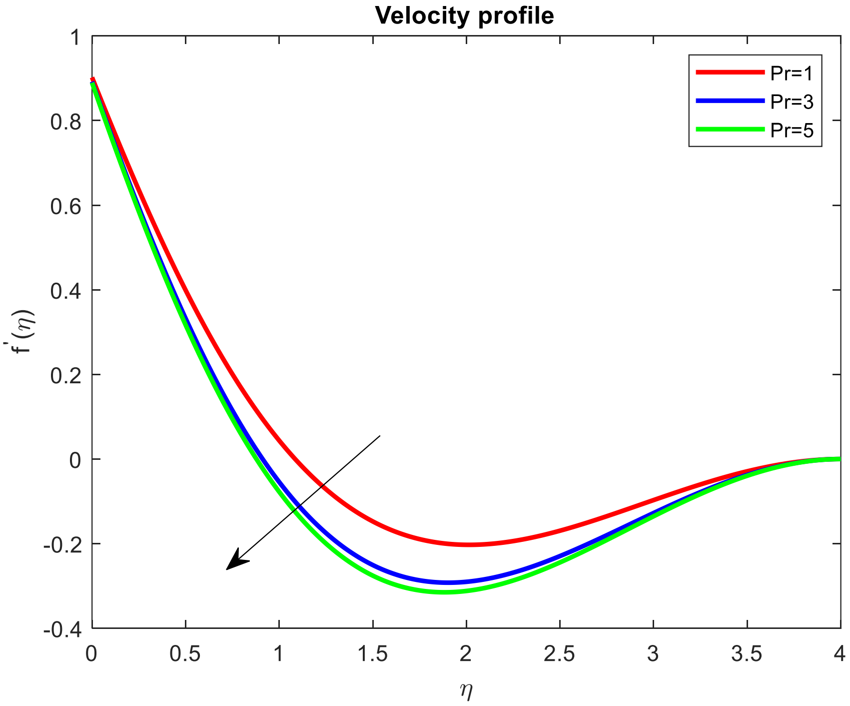

Fig 4(a). Variation of Prandtl number on velocity profile

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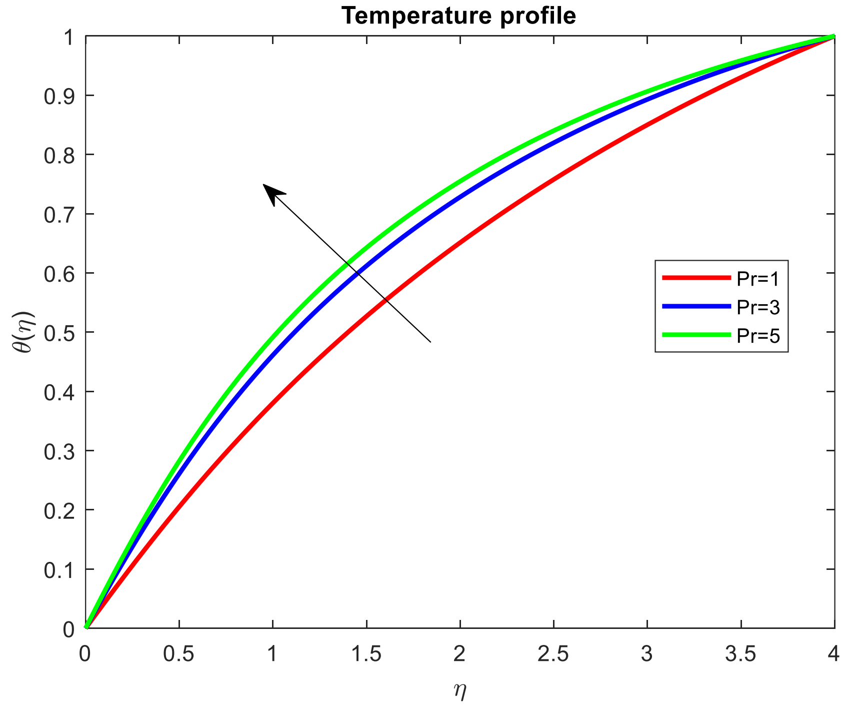

Fig 4(b). Variation of Prandtl number on temperature profile

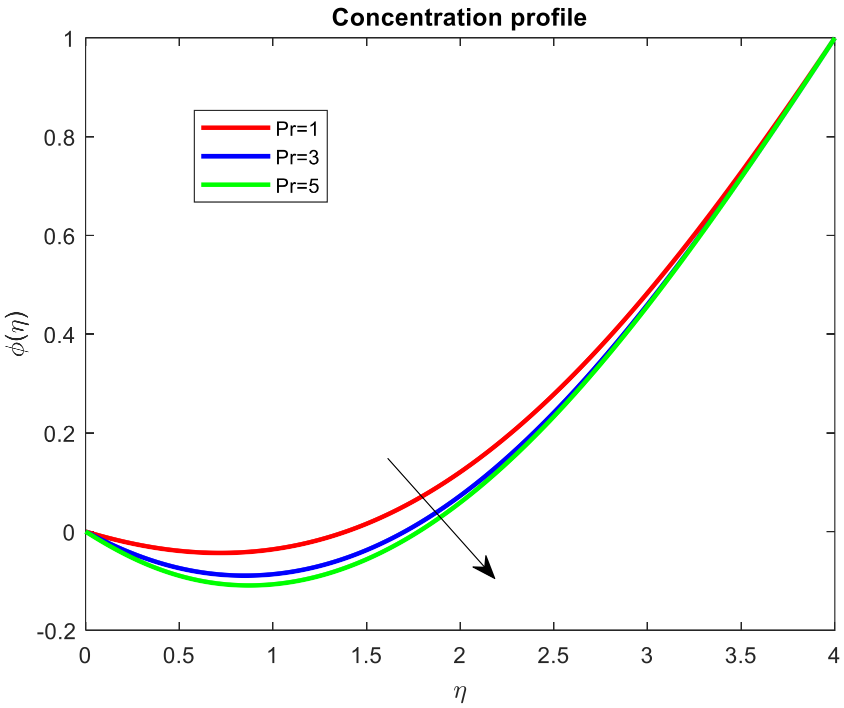

Fig 4(c). Variation of Prandtl number on concentration profile

The influence of the Prandtl number on the velocity, temperature, and concentration profiles is presented in figures 3(a) -3(c). As the Prandtl number increases, the thermal diffusivity of the fluid decreases, resulting in a notable reduction in the temperature profile and a thinner thermal boundary layer. This leads to a sharper temperature gradient near the surface. The velocity profile shows only a minor decrease with increasing Prandtl number, indicating that momentum transport is only slightly affected. However, the concentration profile also exhibits a decreasing trend with increasing Pr, which can be attributed to the reduced thermophoretic force caused by the diminished temperature gradient.

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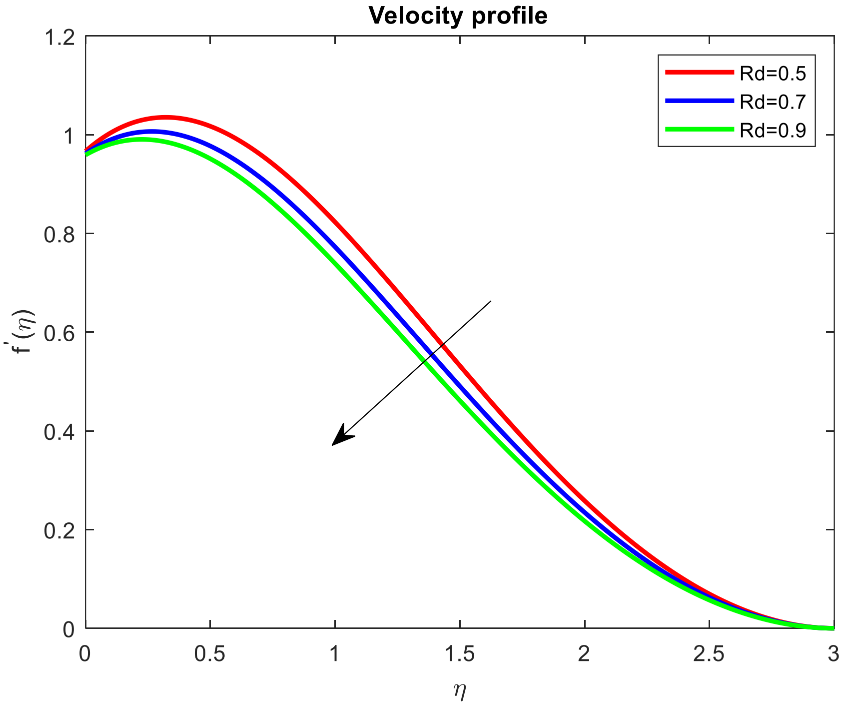

Fig 5(a). Variation of radiation parameterr on velocity profile

Influence of radiation parameter can be seen in the graphs 5(a) – 5(c). An increase in the radiation parameter Rd leads to a noticeable rise in the temperature profile due to intensified radiative heat flux. This elevated thermal energy causes a mild reduction in the velocity profile, as the fluid's momentum is partly absorbed by thermal effects. Simultaneously, the concentration profile increases because higher temperatures enhance nanoparticle diffusion through thermophoresis, leading to greater mass transfer in the boundary layer.

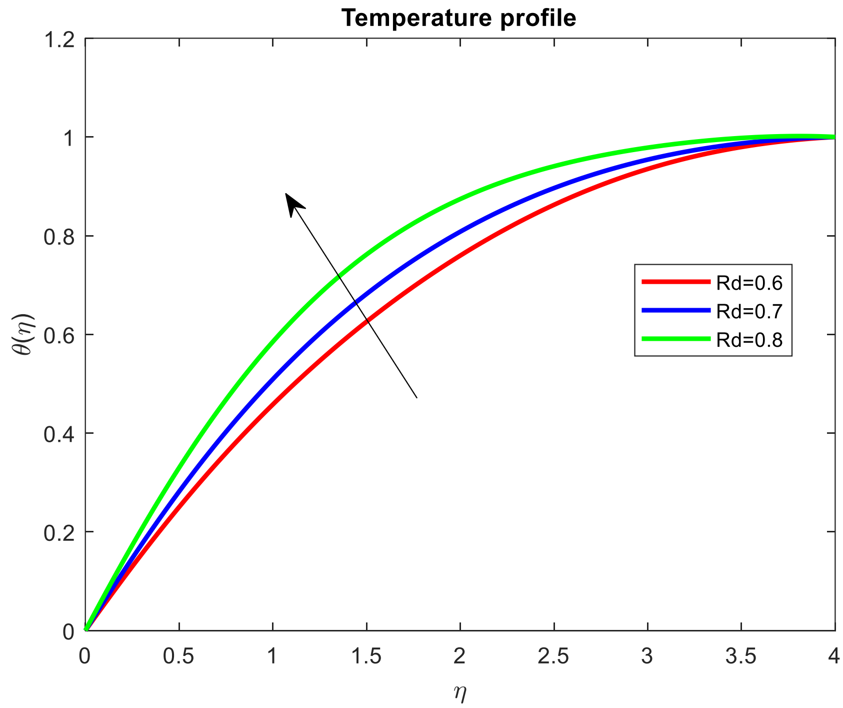

Fig 5(b). Variation of radiation parameter on temperature profile

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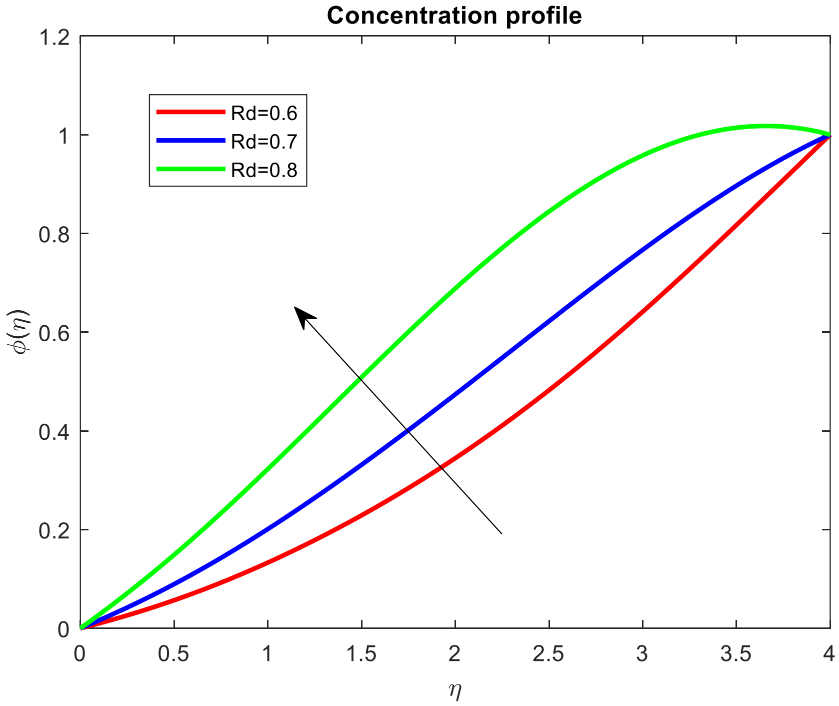

Fig 5(c). Variation of radiation parameterr on concentration profile

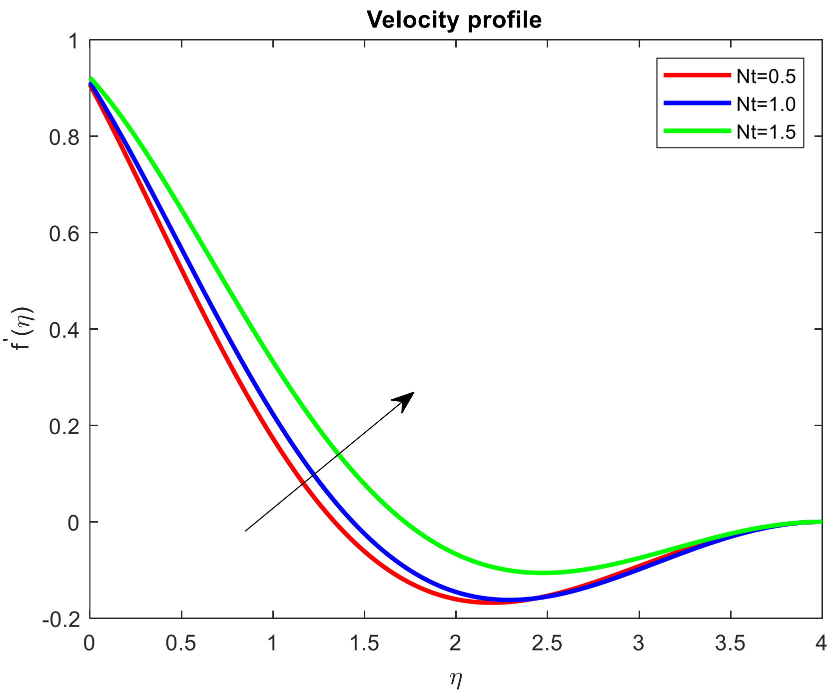

Fig 6(a). Variation of (Nt) Thermophoresis parameter on velocity profile

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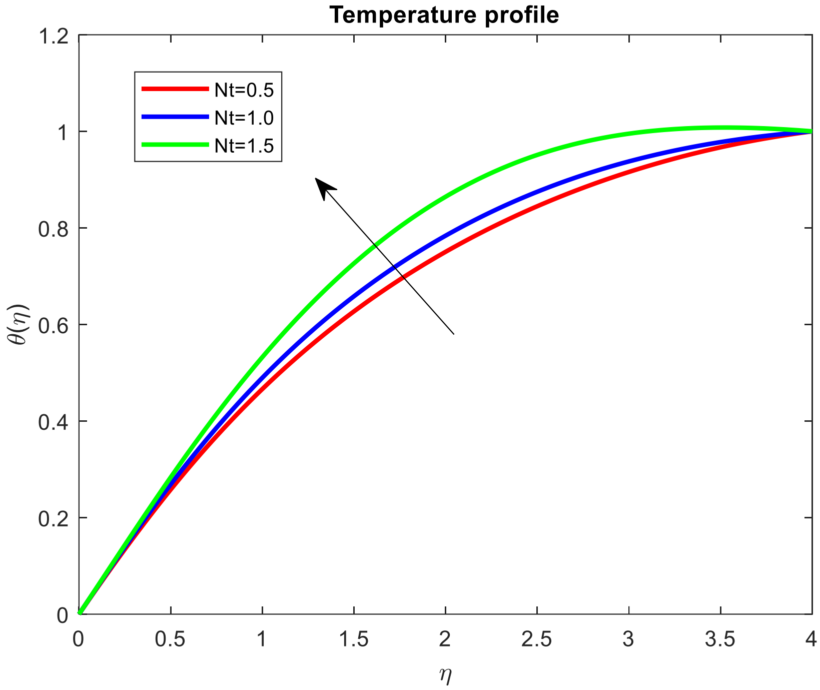

Fig 6(b). Variation of (Nt) Thermophoresis parameter on temperature profile

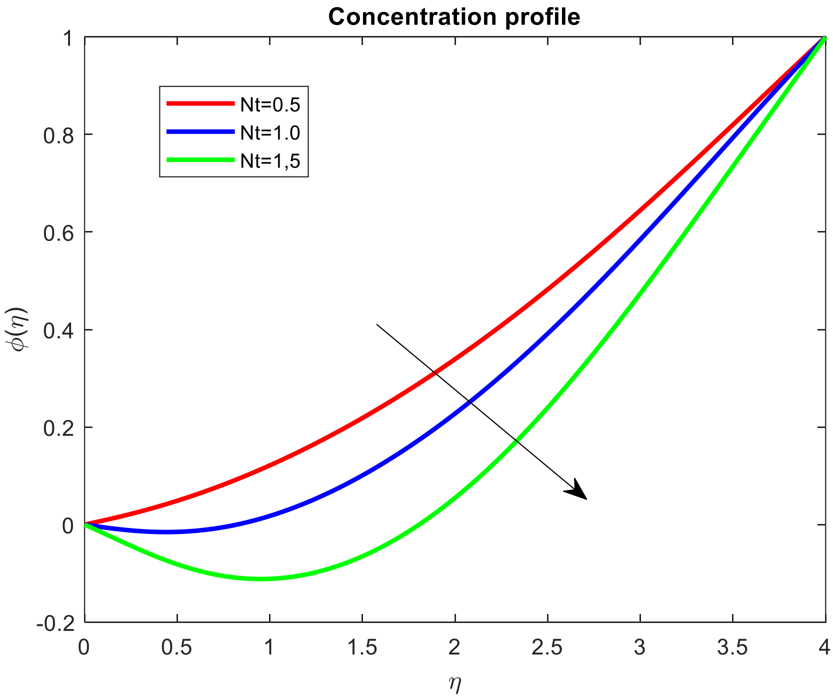

Fig 6(c). Variation of (Nt) Thermophoresis parameter on concentration profile

Variation of Nt os seen in figures 6(a)-6(c). The thermophoresis parameter Nt significantly affects both the temperature and concentration profiles. As Nt increases, the thermophoretic force driven by temperature gradients becomes stronger, causing more nanoparticles to migrate from the hotter surface region toward the cooler areas, this results in an increase in nanoparticle concentration away from the wall and a thickening of the concentration boundary layer leading to a rise in the temperature profile. As a result, the concentration gradient at the wall becomes less steep, slightly reducing the Sherwood number, which indicates a decrease in the mass transfer rate at the surface. However, the effect of Nt on the velocity profile is minimal, as thermophoresis primarily governs heat and mass transfer.

Temperature ratio parameter effect is observed in figures 7(a)-7(c). A higher θ_w intensifies the radiative heat transfer, resulting in an elevated fluid temperature near the wall. This causes the thermal boundary layer to thicken and the temperature gradient at the wall to decrease, ultimately reducing the Nusselt number, which reflects a decrease in

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heat transfer from the surface. Furthermore, the increased temperature strengthens the thermophoretic effects, promoting greater nanoparticle migration away from the heated surface. This leads to a thicker concentration boundary layer and an increase in the Sherwood number, indicating improved mass transfer. Additionally, the rise in temperature can slightly enhance the fluid velocity due to reduced viscosity.

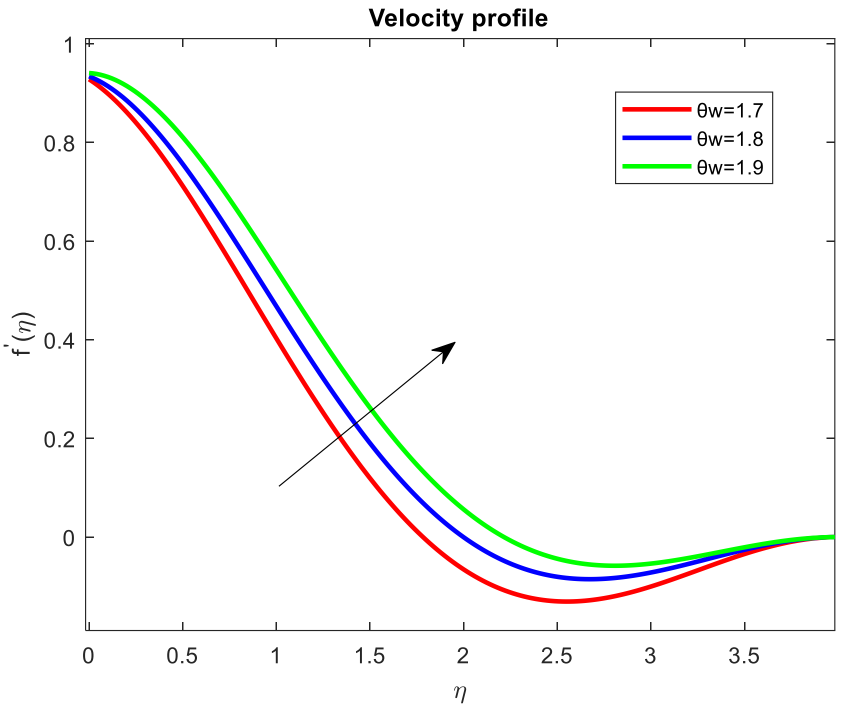

Fig 7(a). Variation of (θ_w) temperature ratio parameter on velocity profile

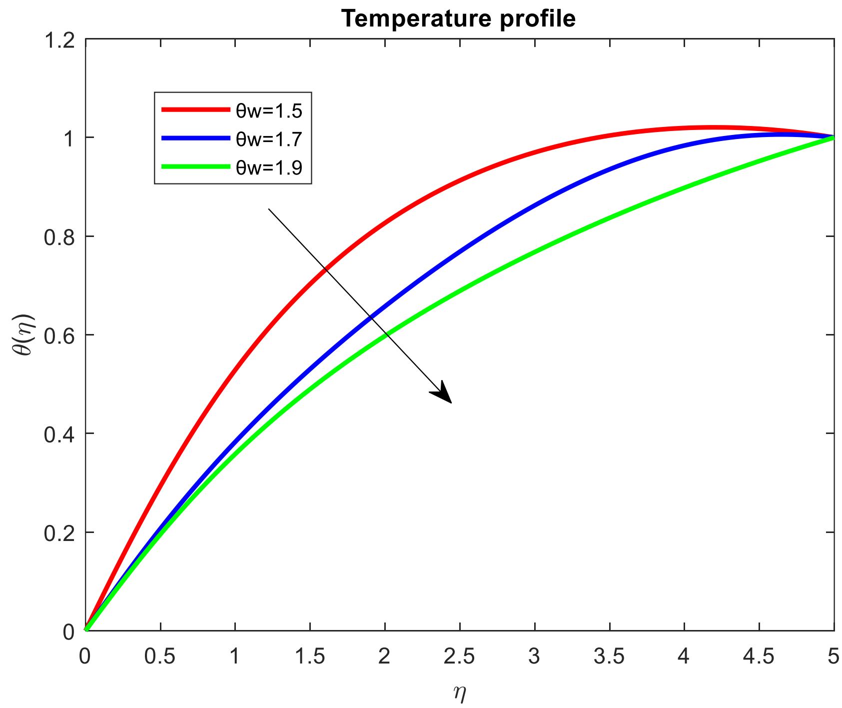

Fig 7(b). Variation of (θ_w) temperature ratio parameter on velocity profile

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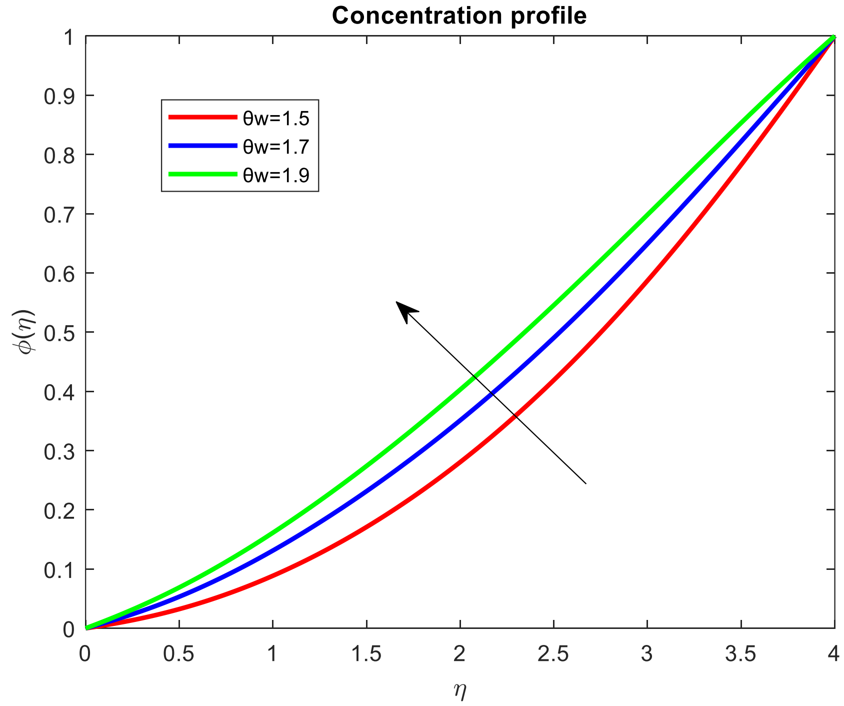

Fig 7(c). Variation of (θ_w) temperature ratio parameter on velocity profile

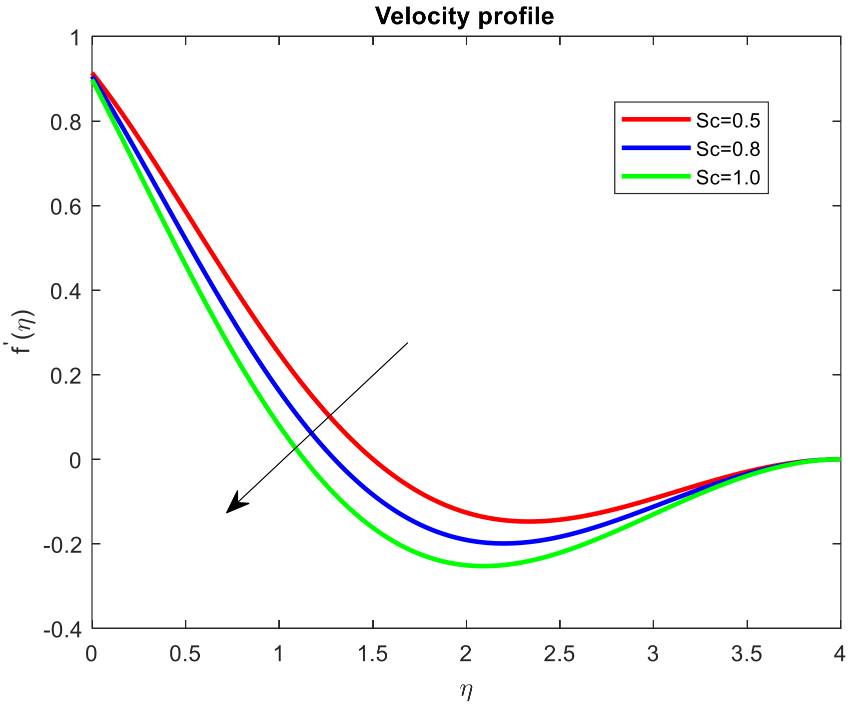

Fig 8(a). Variation of (Sc) Schmidt number on velocity profile

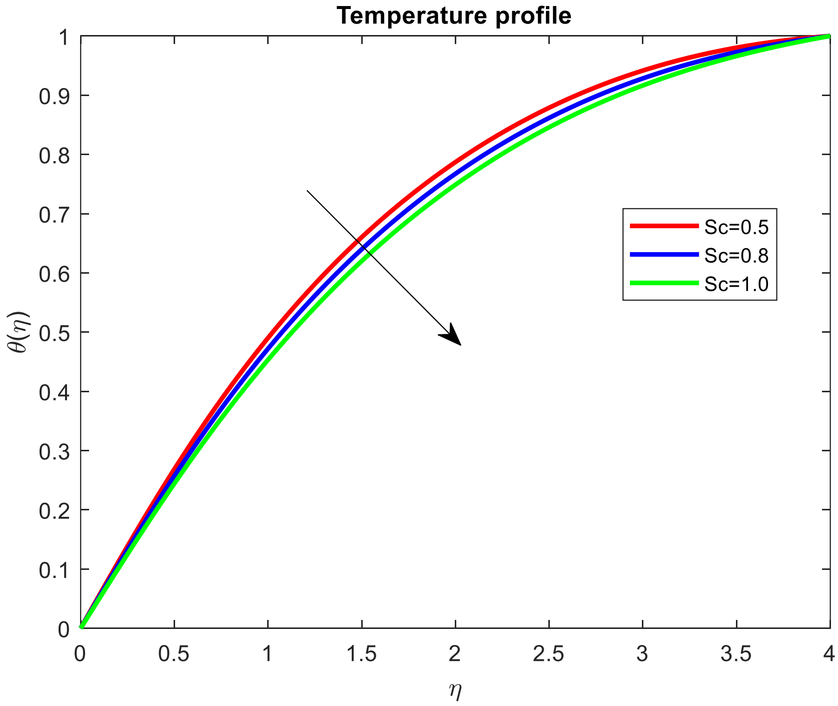

Fig 8(b). Variation of (Sc) Schmidt number on temperature profile

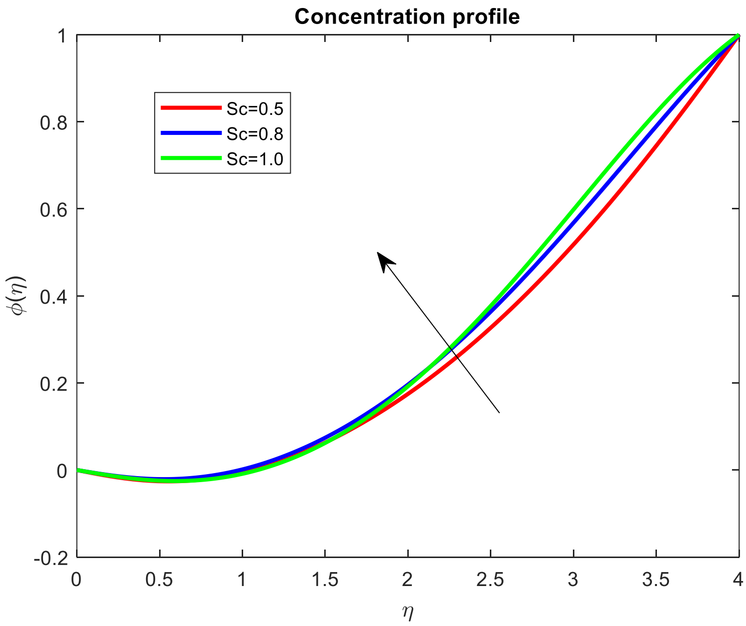

Fig 8(c). Variation of (Sc) Schmidt number on concentration profile

The effects of the Schmidt number (Sc) on the velocity, temperature and concentration profiles are shown in Figs. 8(a) - 8(c). It is evident that as Sc increases, the temperature profile decreases, while the nanoparticle volume fraction and the thickness of its boundary layer increase significantly. Physically, Sc represents the relative influence of thermal diffusion to species diffusion in the boundary layer. An increase in Sc leads to a reduction in the thermal boundary layer thickness, accompanied by a decrease in temperature and an increase in mass transfer rate. he velocity profile may also slightly decrease near the wall due to increased resistance from the thicker concentration boundary layer.

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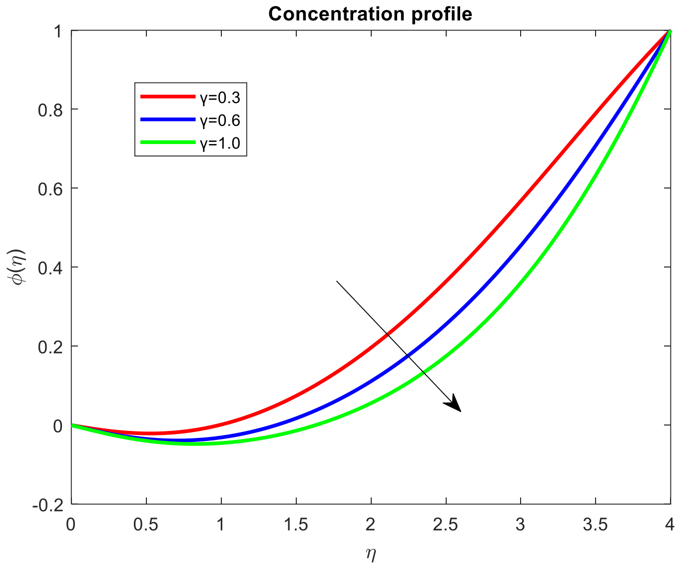

Fig 9(c). Variation of (γ) chemical reaction parameter on concentration profile

The influence of the chemical reaction parameter (γ_r) on concentration profile seen in figure 9(c). The chemical reaction parameter (γ_r) plays a key role in controlling the nanoparticle concentration distribution. As γ_r increases, the reaction rate intensifies, causing a greater depletion of nanoparticles near the wall. This leads to a thinner concentration boundary layer and a steeper concentration gradient at the surface, thereby increasing the Sherwood number and enhancing mass transfer.

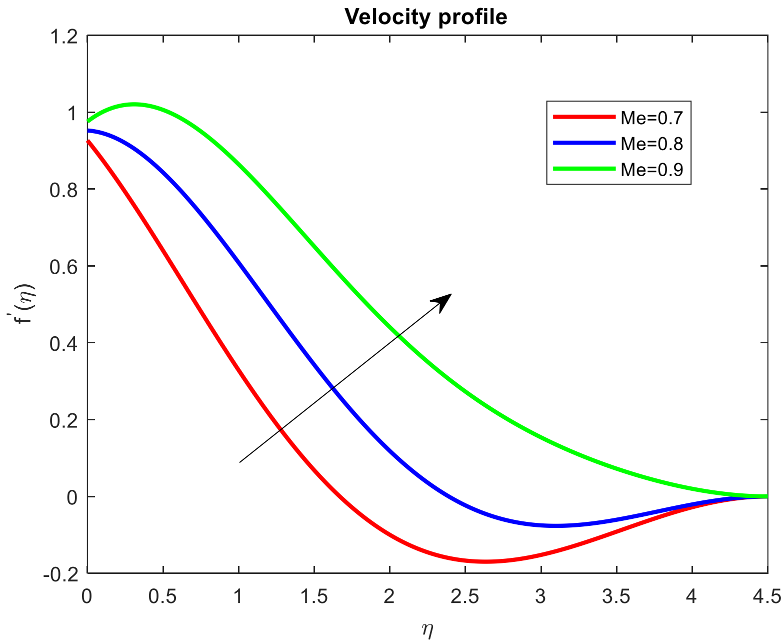

Fig 10(a). Variation of (Me) Melting parameter on velocity profile

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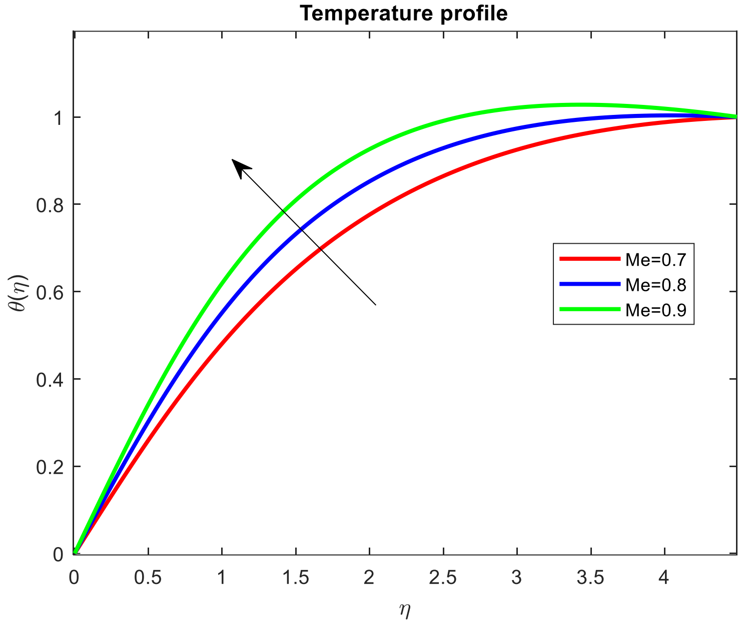

Fig 10(b). Variation of (Me) Melting parameter on temperature profile

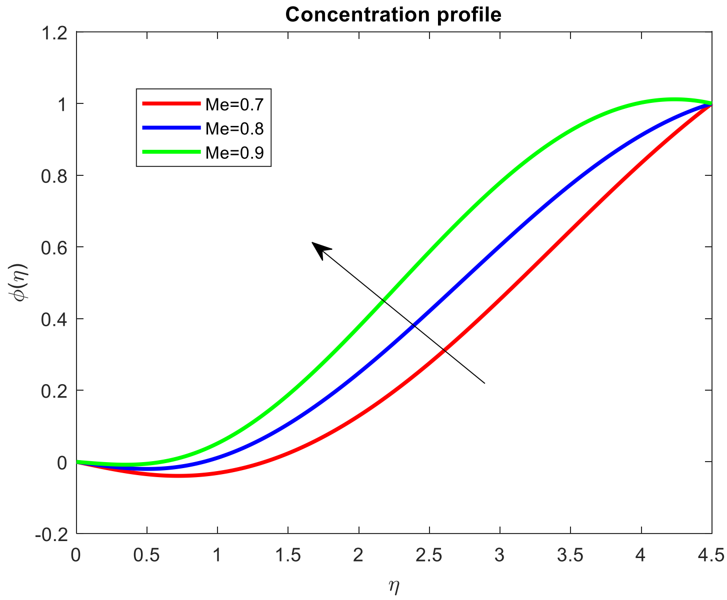

Fig 10(c). Variation of (Me) Melting parameter on concentration profile

The influence of melting parameter Me on velocity, temperature and concentration profiles is shown in fig. 10(a)-10(c). As Me increases, the melting process becomes more dominant, introducing additional thermal energy into the boundary layer. This reduces the thermal resistance at the surface, resulting in a rise in the temperature profile and a thickening of the thermal boundary layer, which results in increase in velocity and temperature distribution. This thermal rise can enhance thermophoretic effects, which drive nanoparticles away from the heated surface, leading to a slight increase in the nanoparticle concentration away from the wall and a thinner concentration boundary layer. Consequently, the concentration gradient at the surface becomes steeper, which can slightly enhance the mass transfer rate.

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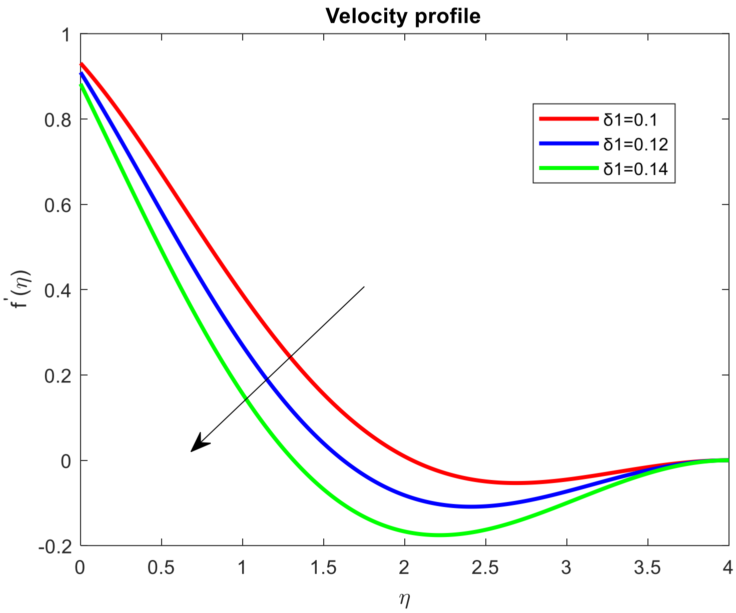

Fig 11(a). Variation of ($\delta 1$) First slip parameter on velocity profile

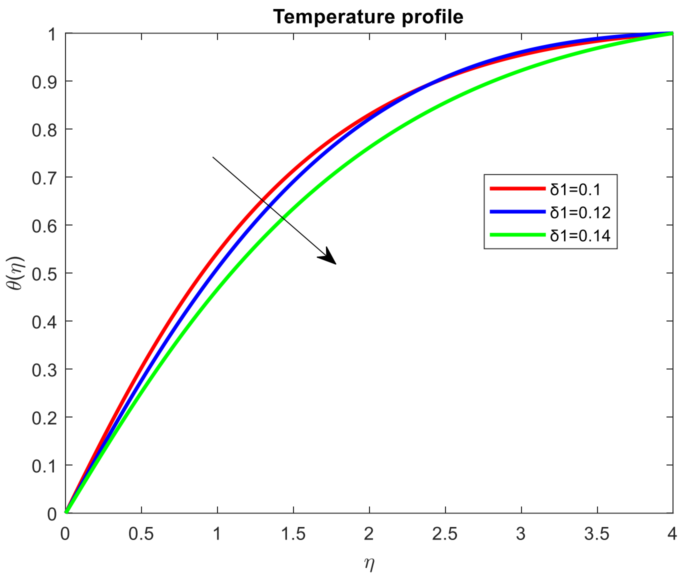

Fig 11(b). Variation of ($\delta 1$) First slip parameter on temperature profile

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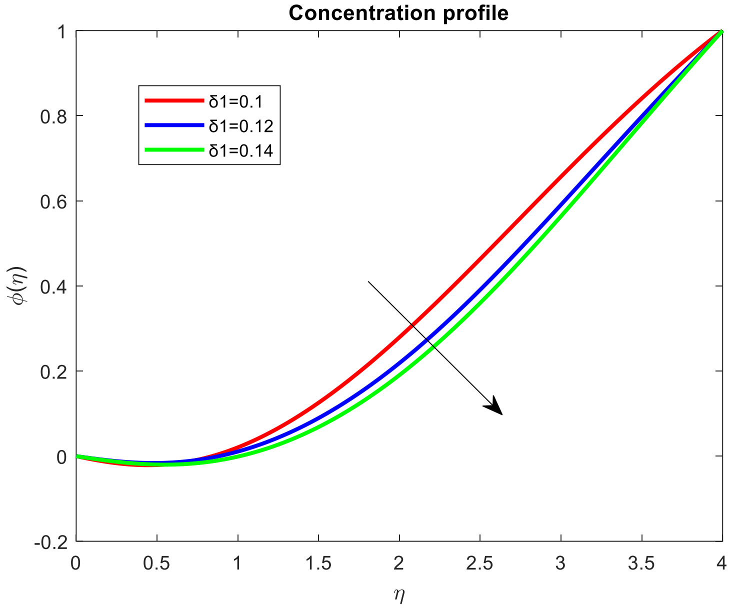

Fig 11(c). Variation of ($\delta 1$) First slip parameter on concentration profile

The impact of first order slip (δ1) effect is observed in figures 11(a)-11(c). The first order velocity slip parameter δ1 reduces the wall-adhering fluid velocity by allowing partial fluid slippage at the boundary, deviating from the classical no-slip condition. As δ1 increases, the velocity gradient at the wall decreases, leading to a reduction in shear stress and skin friction coefficient. This slip also weakens the momentum transfer from the surface to the fluid, resulting in a lower velocity profile near the wall. While the effect on temperature and concentration profiles is indirect, the reduced wall shear can slightly alter the thermal and solutal boundary layers by modifying the flow structure.

Influence of second order slip parameter is observed in figures 12(a)-12(c). The second-order slip parameter δ2 introduces a nonlinear correction to the velocity slip at the surface, further relaxing the no-slip condition. As δ2 increases, the wall shear stress and velocity gradient at the surface decrease more noticeably compared to first-order slip, resulting in a greater reduction in the fluid velocity near the boundary. This enhanced slip weakens momentum transfer from the surface, leading to a thinner velocity boundary layer. Although the second-order slip primarily affects the velocity field, it can also indirectly influence the temperature and concentration distributions by altering the flow structure and convective transport.

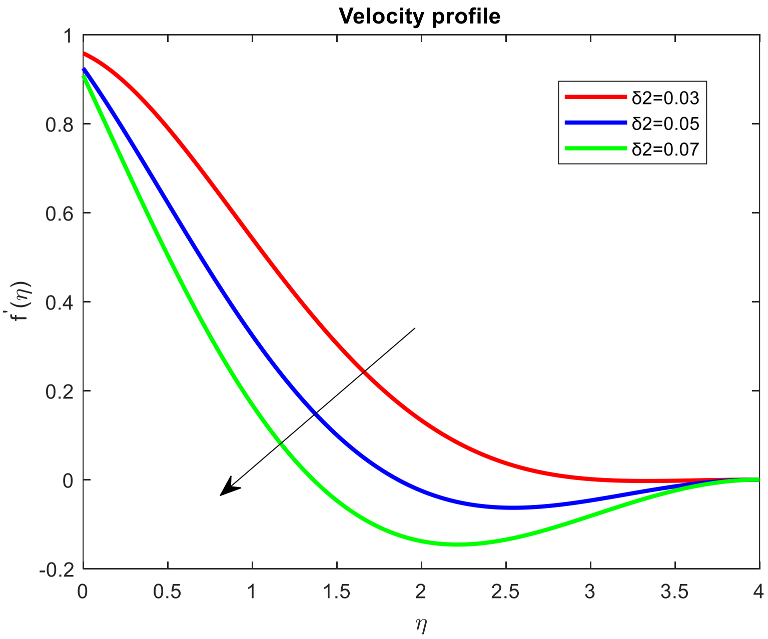

Fig 12(a). Variation of ($\delta 2$) second order slip parameter on velocity profile

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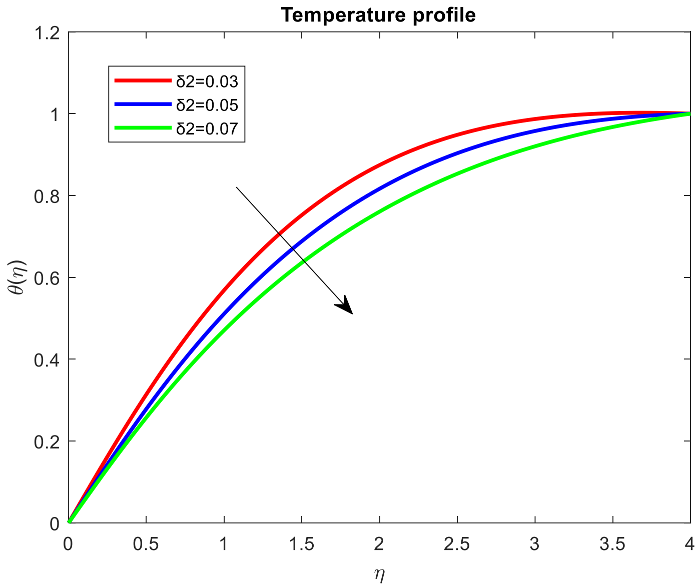

Fig 12(b). Variation of ($\delta 2$) second order slip parameter on temperature profile

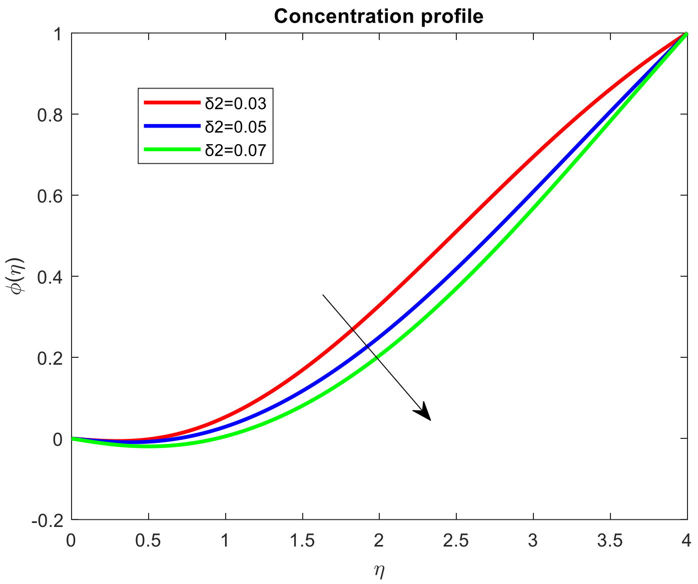

Fig 12(c). Variation of ($\delta 2$) second order slip parameter on concentration profile

Conclusion

An analysis to study the effect of nonlinear thermal radiation on second order slip flow and melting heat transfer of couple stress nanofluid over a nonlinear stretching sheet with chemical reaction is presented. The dimensionless partial differential equations are transformed into a system of first-order ordinary differential equations using similarity transformations. These equations are then numerically integrated using MATLAB's BVP4C solver in conjunction with the shooting method. The influence of key flow parameters is illustrated through graphical results, and the major findings of the analysis are as below.

- The first- and second-order velocity slip parameters weaken fluid–surface interaction, reduce momentum boundary layer thickness, and thus lower the fluid velocity.
- The radiation and melting parameters enhance both temperature and concentration profiles, while radiation reduces the velocity profile and the melting parameter increases.
- The temperature ratio parameter increases velocity and concentration profiles but reduces the temperature profile.
- The couple stress parameter elevates temperature and concentration distributions but leads to a reduction in velocity.
- The Schmidt and Prandtl numbers reduce the velocity profiles while enhancing the temperature and concentration distributions.
- The magnetic parameter suppresses velocity and temperature profiles but enhances the concentration profile.

- Higher reaction rates reduce wall nanoparticle concentration, thin the boundary layer, which intern increase the Sherwood number.

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Original Article

Graph Theoretic Modeling and Spectral Energy Analysis of Some Phytochemical Compounds

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Abstract

Chemical graph theory provides a powerful framework for modeling molecular structures using graph-theoretic concepts and matrix representations. In this paper, we investigate the structural and spectral properties of hydrogen-suppressed molecular graphs corresponding to representative phytochemicals belonging to three major classes: flavonoids, phenolic compounds, and alkaloids. Quercetin, gallic acid, and caffeine are selected as prototypical examples. For each molecular graph, adjacency, degree and Laplacian matrices are constructed, and fundamental invariants such as diameter, eccentricity and Wiener index are examined. Several structural corollaries concerning connectivity, pendant vertices, eccentricity, and spectral characteristics are established. The results illustrate how graph-theoretic descriptors capture essential topological features of phytochemical molecules and provide a unified mathematical approach for their comparative analysis. ***[1–5, 7–10].***

Keywords: *Chemical graph theory Hydrogen-suppressed molecular graphs, Spectral graph invariants, Phytochemicals.*

Introduction

Phytochemicals are naturally occurring chemical compounds found in plants and are widely recognized for their biological and pharmacological activities, including antioxidant, anti-inflammatory, and neurostimulatory effects. From a mathematical perspective, the structural complexity of these compounds can be efficiently analyzed using chemical graph theory [1,2], where molecules are represented as graphs whose vertices correspond to atoms and edges correspond to chemical bonds.

Graph-theoretic modeling of molecular structures has gained significant attention due to its applications in quantitative structure–activity relationships (QSAR), molecular descriptor computation, and spectral analysis [2,6,7]. Matrix representations such as adjacency, Laplacian, distance, and distance Laplacian matrices encode both local and global structural information of molecules and allow the derivation of meaningful numerical invariants [3,4,5,8].

The objective of this work is to present a systematic graph-theoretic study of selected phytochemicals from three major classes:

- flavonoids (quercetin),
- phenolic compounds (gallic acid), and
- alkaloids (caffeine).

By constructing hydrogen-suppressed molecular graphs and analyzing their associated matrices and spectral parameters, we demonstrate how mathematical tools can be applied to understand molecular topology in a unified and rigorous manner.

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Preliminaries and Definitions

Let $G = (V, E)$ be a simple connected graph of order $n =| V |$ and size $m =| E |$.

Definition 2.1.1: For vertices $v_i, v_j \in V(G)$, the **distance** between them, denoted by $d(v_i, v_j)$, is the length of the shortest path joining $v_i$and v_j. The **distance matrix** of $G$is the matrix
$D(G) = (d_{ij}), d_{ij} = d(v_i, v_j)$ [1,2,8].

Definition 2.1.2: The **diameter** of a graph G, denoted by diam (G), is the maximum distance between any pair of vertices of G. [1]

Definition 2.1.3: The **transmission** (or status) of a vertex $v_i$is defined as

$$t_G(v_i) = \sum_{v_j \in V(G)} d(v_i, v_j).$$

A graph is called k-transmission regular if $t_G(v) = k$ for every $v \in V(G)$.

Definition 2.1.4: The diagonal matrix

$$T(G) = \text{diag}\ (t(v_1), t(v_2), \dots, t(v_n))$$

is called the transmission matrix of G. [3,4,8]

Definition 2.1.5: Adjacency Matrix of a graph

The adjacency matrix of $G$is the matrix

$$A(G) = (a_{ij}), \quad a_{ij} = \begin{Bmatrix} 1, & \text{if } v_i, v_j \in E(G) \\ 0, & otherwise \end{Bmatrix} \text{ [1].}$$

Definition 2.1.6: Laplacian Matrix of a Graph

Let $G = (V, E)$ be a simple, undirected graph with vertex set $V(G) = \{v_1, v_2, \dots, v_n\}$.
The Laplacian matrix of G, denoted by $L(G)$, is defined as $L(G) = D(G) - A(G)$
Where $A(G) = [a_{ij}]$is the adjacency matrix of G, with

$$a_{ij} = \begin{cases} 1, & \text{if } v_i \text{ is adjacent to } v_j, \\ 0, & \text{otherwise;} \end{cases}$$

$D(G) = \text{diag}(d_1, d_2, \dots, d_n)$ is the degree matrix, where d_i is the degree of vertex v_i. **[1,4,5]**

Definition 2.1.7: Laplacian Energy

For a graph G with Laplacian matrix $L(G)$ and eigenvalues $\mu_1, \mu_2, \dots, \mu_n$, the Laplacian energy is defined as:

$$\boldsymbol{LE(G)} = \sum_{i=1}^{n} | \boldsymbol{\mu_i} - \frac{\boldsymbol{2m}}{\boldsymbol{n}} | = \sum_{i=1}^{n} | \lambda_i - \bar{d} |$$

where m is the number of edges. [1,5,9]

Definition 2.1.8: Distance Laplacian Matrix of a Graph

The distance Laplacian matrix of G is defined as

$$D^L(G) = \text{Tr}\ (G) - D(G).$$

where $D(G)$is the distance matrix and $Tr(G)$is the diagonal matrix of vertex transmissions. [3,4,8]

Definition 2.1.9: Distance Laplacian Energy

Let $\lambda_1, \lambda_2, \dots, \lambda_n$be the eigenvalues of $D^L(G)$. The Distance Laplacian Energy (DLE) of $G$is

$$DLE(G) = \sum_{i=1}^{n} | \lambda_i - \frac{2W}{n} |$$

Where $W = \sum_{i<j} d_{ij}$ is the **Wiener index** (sum of all pairwise distances). [3,4,10]

Definition 2.1.10: Molecular Graph

A molecular graph is a finite connected labeled graph obtained by representing non-hydrogen atoms as vertices and covalent bonds as edges. [2,6]

Examples of Major Phytochemical Classes

To illustrate the diversity of phytochemicals and their structural features, representative examples from major phytochemical classes are summarized below. [2,6,7]

3.1: Flavonoids

Example: Quercetin

Chemical formula: $C_{15}H_{10}O_7$

Chemical Structure:

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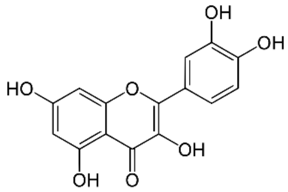

Quercetin possesses the characteristic flavonoid backbone consisting of a **C_6–C_3–C_6** skeleton, where two benzene rings (rings A and B) are connected through a heterocyclic pyran ring (ring C). The presence of multiple hydroxyl (–OH) groups contributes to its strong antioxidant activity. [6,7]

3.1.1: Hydrogen-suppressed molecular graph of Quercetin

Given molecular formula: $C_{15}H_{10}O_7$

Structure of **Quercetin:** Quercetin is **3,3′,4′,5,7-pentahydroxyflavone**, consisting of:

- **Ring A (benzene):** 6 carbons
- **Ring B (benzene):** 6 carbons
- **Ring C (heterocycle):** 3 carbons + 1 oxygen
- **Carbonyl oxygen:** 1
- **Five hydroxyl oxygen:** 5

Total oxygen atoms = **7**

Let G be a **hydrogen-suppressed molecular graph of Quercetin**

- **Vertices** ⟺ non-hydrogen atoms
- **Edges** ⟺ covalent bonds between those atoms
- **Hydrogen atoms are omitted**

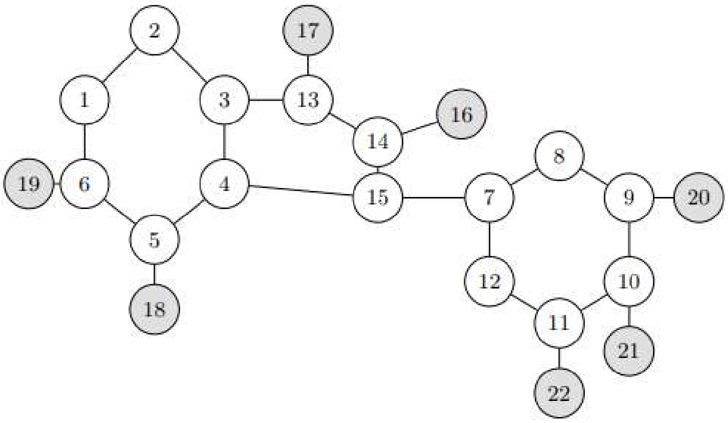

Figure 1: Hydrogen-suppressed molecular graph of quercetin ($C_{15}H_{10}O_7$).

Order of the Graph: Non-hydrogen atoms in quercetin:

Atom	Number
Carbon (C)	15
Oxygen (O)	7
Total vertices	**22**

Therefore, $|V(G)| = 22$

Vertex Labeling: Let us label the vertices as $V(G) = \{v_1, v_2, v_3, \dots \dots v_{22}\}$

- $v_1 - v_{15}$: carbon atoms
- $v_{16} - v_{22}$: oxygen atoms

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3.1.2: Adjacency Matrix of hydrogen-suppressed molecular graph of Quercetin

$$A(G) =$$

$$A(G) =$$

$$\begin{pmatrix}
0&1&0&0&0&1&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
1&0&1&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&1&0&1&0&0&0&0&0&0&0&0&1&0&0&0&0&0&0&0&0&0\\
0&0&1&0&1&0&0&0&0&0&0&0&0&0&1&0&0&0&0&0&0&0\\
0&0&0&1&0&1&0&0&0&0&0&0&0&0&0&0&0&1&0&0&0&0\\
1&0&0&0&1&0&0&0&0&0&0&0&0&0&0&0&0&0&1&0&0&0\\
0&0&0&0&0&0&0&1&0&1&0&1&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&1&0&1&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&1&0&1&0&0&0&0&0&0&0&0&0&1&0&0\\
0&0&0&0&0&0&0&0&1&0&1&0&0&0&0&0&0&0&0&0&1&0\\
0&0&0&0&0&0&0&0&0&1&0&1&0&0&0&0&0&0&0&0&0&1\\
0&0&0&0&0&0&1&0&0&0&1&0&0&0&0&0&0&0&0&0&0&0\\
0&0&1&0&0&0&0&0&0&0&0&0&0&1&0&0&1&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&1&0&1&1&0&0&0&0&0&0\\
0&0&0&1&0&0&1&0&0&0&0&0&0&1&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&1&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&1&0&0&0&0&0&0&0&0&0\\
0&0&0&0&1&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&1&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&1&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&1&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&1&0&0&0&0&0&0&0&0&0&0&0
\end{pmatrix}_{22X22}$$

Observation:

Adjacency Matrix of hydrogen-suppressed molecular graph of Quercetin is **symmetric**

Degree matrix: The degree matrix is diagonal, $\boldsymbol{D(G) = diag(d_1, d_2, \dots \dots . d_{22})}$

$$\boldsymbol{D(G) = diag(2,2,3,3,3,3,3,2,3,3,3,2,3,3,3,1,1,1,1,1,1,1)}$$

3.1.3: Laplacian Matrix of hydrogen-suppressed molecular graph of Quercetin

Let $G = (V, E)$be a simple, undirected graph with vertex set $V(G) = \{v_1, v_2, \dots, v_{22}\}$.

The Laplacian matrix of G, denoted by $L(G)$, is defined as $L(G) = D(G) - A(G)$

Where $A(G) = [a_{ij}]$is the adjacency matrix of G, with

$$a_{ij} = \begin{cases} 1, & \text{if } v_i \text{ is adjacent to } v_j, \\ 0, & \text{otherwise;} \end{cases}$$

$D(G) = \mathrm{diag}(d_1, d_2, \dots, d_n)$is the degree matrix, where $d_i$is the degree of vertex v_i.[1]

$$L(G) =$$

$$\begin{pmatrix}
2&-1&0&0&0&-1&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
-1&2&-1&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&-1&3&-1&0&0&0&0&0&0&0&0&-1&0&0&0&0&0&0&0&0&0\\
0&0&-1&3&-1&0&0&0&0&0&0&0&0&0&-1&0&0&0&0&0&0&0\\
0&0&0&-1&3&-1&0&0&0&0&0&0&0&0&0&0&0&-1&0&0&0&0\\
-1&0&0&0&-1&3&0&0&0&0&0&0&0&0&0&0&0&0&-1&0&0&0\\
0&0&0&0&0&0&3&-1&0&-1&0&-1&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&-1&2&-1&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&-1&3&-1&0&0&0&0&0&0&0&0&0&-1&0&0\\
0&0&0&0&0&0&0&0&-1&3&-1&0&0&0&0&0&0&0&0&0&-1&0\\
0&0&0&0&0&0&0&0&0&-1&3&-1&0&0&0&0&0&0&0&0&0&-1\\
0&0&0&0&0&0&-1&0&0&0&-1&2&0&0&0&0&0&0&0&0&0&0\\
0&0&-1&0&0&0&0&0&0&0&0&0&3&-1&0&0&-1&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&-1&3&-1&-1&0&0&0&0&0&0\\
0&0&0&-1&0&0&-1&0&0&0&0&0&0&-1&3&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&-1&0&1&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&-1&0&0&0&1&0&0&0&0&0\\
0&0&0&0&-1&0&0&0&0&0&0&0&0&0&0&0&0&1&0&0&0&0\\
0&0&0&0&0&-1&0&0&0&0&0&0&0&0&0&0&0&0&1&0&0&0\\
0&0&0&0&0&0&0&0&-1&0&0&0&0&0&0&0&0&0&0&1&0&0\\
0&0&0&0&0&0&0&0&0&-1&0&0&0&0&0&0&0&0&0&0&1&0\\
0&0&0&0&0&0&0&0&0&0&-1&0&0&0&0&0&0&0&0&0&0&1
\end{pmatrix}_{22X}$$

3.1.3: Corollary

Let G be the hydrogen-suppressed molecular graph of quercetin. Then G is connected and has diameter

$$diam(G) = 8.$$

Proof:

Each pendant oxygen vertex $v_{16}, \dots, v_{22}$. is adjacent to a carbon vertex that lies on one of the three fused rings. Since

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Rings A, B, and C form a connected backbone and all oxygen vertices are attached to this backbone, there exists a path between every pair of vertices. The longest shortest path occurs between pendant oxygen vertices attached to opposite benzene rings, yielding a maximum distance of 8. **[4,5]**

3.1.4: Corollary 2. For each pendant oxygen vertex v_i $i = 16, \ldots, 22$, the eccentricity satisfies $\varepsilon(v_i) \geq 4$

Proof:

Each v_i is of degree one and adjacent to a carbon atom within the ring system. Any shortest path from v_i to vertices in the opposite benzene ring must traverse the heterocyclic ring and at least one additional ring, implying a path length of at least four edges**. [3,4]**

3.1.5: Corollary 3. The subgraph induced by the carbon vertices $v_1, \ldots, v_{15}$ contains no pendant vertices.

Proof:

Each carbon vertex lies on at least one cycle (Ring A, B, or C) or serves as a connecting vertex between rings. Hence, every carbon vertex has degree at least two in the induced subgraph.[2]

3.1.6: Corollary 4. Let $W(G)$ denote the Wiener index of the quercetin graph. Then

$$\boldsymbol{W(G) \geq \sum_{i=1}^{22} \varepsilon(v_i)}$$

Proof:

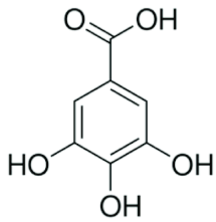
Each pendant oxygen vertex contributes at least its eccentricity to the sum of distances from that vertex to all others. Since $\boldsymbol{\varepsilon(v_i)} \geq \mathbf{4}$, the cumulative contribution of pendant vertices yields the stated lower bound. [3,10]

3.2: Phenolic Compounds

Example: Gallic acid

Chemical formula: $C_7H_6O_5$

Chemical Structure:



Gallic acid consists of a benzene ring substituted with **three hydroxyl groups and one carboxy group,** making it a simple yet potent phenolic antioxidant. [6,7]

Molecule: Gallic acid

Chemical formula: $C_6H_7O_5$

Class: Phenolic compound

Molecular Structure: Gallic acid = **3,4,5-trihydroxybenzoic acid**

Key structural features

- One **benzene ring** (6 carbons)
- One **carboxyl group** (−COOH)
- Three **phenolic OH groups**
- Hydrogen-suppressed → hydrogens omitted

Order of the molecular graph

Atom	Number
Carbon (C)	7
Oxygen (O)	5
Total vertices	**12**

Therefore, $|V(G)| = 12$

Hence,

Adjacency matrix order: 12×12

Vertex labeling: Let $V(G) = \{v_1, v_2, \ldots, v_{12}\}$.

Carbon atoms: $\{v_1, v_2, \ldots, v_7\}$.

Oxygen atoms: $\{v_8, v_9, \ldots, v_{12}\}$.

Carbon framework

- Benzene ring: $(\{v_1, v_2, v_3, v_4, v_5, v_6, , v_1\}$
- Carboxyl carbon attached to ring: (v_1, v_7).

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Carbon–oxygen bonds

- Carbonyl oxygen: (v_1, v_7).
- Hydroxyl oxygen of COOH: (v_7, v_9).
- Three phenolic OH groups: (v_3, v_{10}), (v_4, v_{11}), (v_5, v_{12}).

Edge S et:

$E(G) = \{(v_1, v_2), (v_2, v_3), (v_3, v_4), (v_5, v_6), (v_6, v_1), (v_1, v_7), (v_7, v_9), (v_3, v_{10}), (v_4, v_{11}), (v_5, v_{12})\}$.

Hydrogen-suppressed Molecular Graph of Gallic Acid $C_6H_7O_5$

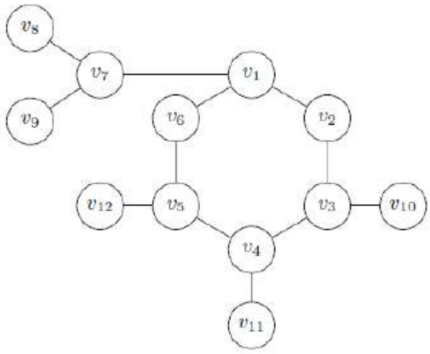

figure 2: **Hydrogen-suppressed Molecular Graph of Gallic Acid** $(C_6H_7O_5)$.

3.2.1: Adjacency Matrix of hydrogen-suppressed molecular graph of Gallic Acid

$$A(G) = \begin{pmatrix} 0 & 1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix}_{12X12}$$

Observation:

Adjacency Matrix of hydrogen-suppressed molecular graph of Gallic Acid is **symmetric**

Degree matrix:

The **degree matrix** is diagonal: $D(G) = diag(d_1, d_2, \dots \dots . d_{12})$

$$\boldsymbol{D(G) = diag(3, 2, 3, 3, 3, 2, 3, 1, 1, 1, 1, 1)}$$

3.2.2: Laplacian Matrix of hydrogen-suppressed molecular graph of Gallic Acid

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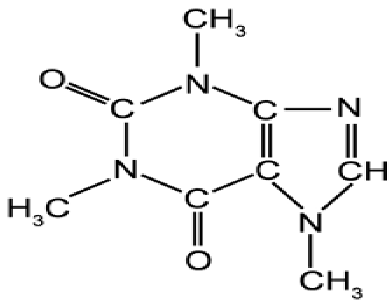
$$L(G) = \begin{pmatrix} 3 & -1 & 0 & 0 & 0 & -1 & 0 & 0 & 0 & 0 & 0 & 0 \\ -1 & 2 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & -1 & 3 & -1 & 0 & 0 & 0 & 0 & 0 & -1 & 0 & 0 \\ 0 & 0 & -1 & 3 & -1 & 0 & 0 & 0 & 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & -1 & 3 & -1 & 0 & 0 & 0 & 0 & 0 & -1 \\ -1 & 0 & 0 & 0 & -1 & 2 & 0 & 0 & 0 & 0 & 0 & 0 \\ -1 & 0 & 0 & 0 & 0 & 0 & 3 & -1 & -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & -1 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & -1 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{pmatrix}_{12X12}$$

3.2.3: Corollary 1
Let G be the hydrogen-suppressed molecular graph of gallic acid. Then the Laplacian matrix $L(G)$ has exactly **one zero eigenvalue.**
Proof.
From the adjacency matrix and distance matrix, the graph G is connected. By a classical result in spectral graph theory, the multiplicity of the eigenvalue 0 of $L(G)$ equals the number of connected components of G. Hence, $L(G)$ has exactly one zero eigenvalue. [4,5]
3.2.4: Corollary 2
All pendant oxygen vertices $v_8, v_9, v_{10}, v_{11}, v_{12}$ have **maximum eccentricity** in G.
Proof.
Each pendant vertex has degree 1 and is attached to a non-pendant vertex of the aromatic core. For any pendant vertex v, every shortest path to distant vertices must pass through its unique neighbor, increasing distances by at least one compared to core vertices. From the distance matrix, these vertices attain the maximum row sum and maximum distance value. Hence, pendant oxygen vertices have maximum eccentricity. [3,8]
3.3: Alkaloids
Example: Caffeine **Chemical formula:** $C_8H_{10}N_4O_2$

Chemical Structure:



Caffeine contains a **purine ring system** with multiple nitrogen atoms, a defining feature of alkaloids. Its molecular structure underlies its physiological activity as a stimulant. [2,6,7]

Order of the molecular graph

Atom	Number
Carbon (C)	8
Nitrogen (N)	4
Oxygen (O)	2
Total vertices	**14**

Therefore, $|V(G)| = 14$
Hence,
Adjacency matrix order: 14×14
Molecular Graph:

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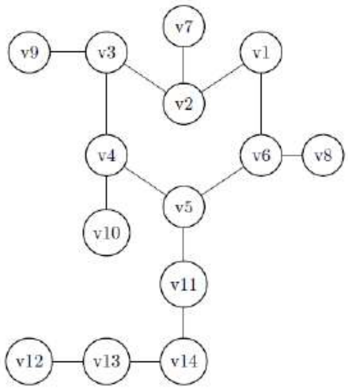

figure 3: Hydrogen-suppressed Molecular Graph of Caffeine ($C_8H_{10}N_4O_2$).

Vertex and Edge Set:

Vertex labeling: Let $\boldsymbol{V(G) = \{v_1, v_2, \dots, v_{14}\}}$.

Edges are placed between vertices that share a chemical bond (single or double; multiplicity ignored in simple graphs).

This gives a **simple, connected, heterocyclic molecular graph** with:

- **14 vertices**
- **15 edges**

2 fused cycles (purine system)

Vertex	v_1	v_2	v_3	v_4	v_5	v_6	v_7	v_8	v_9	v_{10}	v_{11}	v_{12}	v_{13}	v_{14}
Atoms	N_1	C_2	N_3	C_4	N_5	C_6	O_7	O_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}

Edge connectivity

Edges correspond to covalent bonds in caffeine:

$$E(G) = \{v_1 - v_2, v_1 - v_6, v_2 - v_3, v_2 - v_7, v_3 - v_4, v_3 - v_9, v_4 - v_5, v_4 - v_{10}, v_5 - v_6, v_6 - v_8, v_5 - v_{11}, v_{11} - v_{12}, v_{12} - v_{13}, v_{13} - v_{14}\}$$

3.3.1: Adjacency Matrix of hydrogen-suppressed molecular graph of Caffeine

$$A(G) = \begin{pmatrix} 0 & 1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 1 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 1 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 1 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 1 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 1 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \end{pmatrix}_{14X14}$$

Observation:

Adjacency Matrix of hydrogen-suppressed molecular graph of Caffeine is **symmetric**

Degree matrix:

The **degree matrix** is diagonal: $\boldsymbol{D(G) = diag(d_1, d_2, \dots \dots . d_{14})}$

$$\boldsymbol{D(G) = diag(2, 3, 3, 3, 3, 3, 1, 1, 1, 1, 2, 2, 2, 1)}$$

3.3.2: Laplacian Matrix of hydrogen-suppressed molecular graph of Caffeine

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$$L(G) = \begin{pmatrix} 2 & -1 & 0 & 0 & 0 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -1 & 3 & -1 & 0 & 0 & 0 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & -1 & 3 & -1 & 0 & 0 & 0 & 0 & -1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & -1 & 3 & -1 & 0 & 0 & 0 & 0 & -1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & -1 & 3 & -1 & 0 & 0 & 0 & 0 & -1 & 0 & 0 & 0 \\ -1 & 0 & 0 & 0 & -1 & 3 & 0 & -1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & -1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & -1 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & -1 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & -1 & 0 & 0 & 0 & 0 & 0 & 2 & -1 & 0 & 0 \\ 0 & 0 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1 & 2 & -1 & 0 \\ 0 & 0 & 0 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1 & 2 & -1 \\ 0 & 0 & 0 & 0 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1 & 1 \end{pmatrix}_{14X14}$$

3.3.3: Corollary 1: The hydrogen-suppressed m0olecular graph G of caffeine is connected.

Proof:

The Laplacian matrix $L(G)$ has exactly **one zero eigenvalue,** since:

- All diagonal entries are positive,
- Off-diagonal entries correspond to adjacency,
- The degree matrix satisfies $\sum_j L_{ij} = 0$ for each row.

By the **Spectral Connectivity Theorem**, the multiplicity of the zero eigenvalue of $L(G)$ equals the number of connected components of G.Since caffeine is a single molecule and the graph has no isolated components, the multiplicity is one.

Hence, G is connected. [4,5]

3.3.4: Corollary 2: No nitrogen vertex in the caffeine molecular graph is pendant.

Proof:

From the degree sequence:

$$D(G) = diag(2,3,3,3,3,3,1,1,1,1,2,2,2,1)$$

Vertices of degree 1 correspond only to oxygen and methyl carbon atoms.
All nitrogen vertices have $degree\ \geq 2$, hence none is pendant.

3.3.5: Corollary 3: The molecular graph of caffeine contains at least two cycles.

Proof:

For a connected graph,

Cyclomatic number=$|E| - |V| + 1$

Here,

$$|E| = 15, \qquad |V| = 14$$

$$\Rightarrow \text{Cyclomatic number} = 15 - 14 + 1 = 2$$

Thus, the graph contains **exactly two independent cycles**, corresponding to the fused purine rings.

Hence, G is bicyclic. [1,4]

3.4: Compact Table

Phytochemical class	Example	Formula	Key structural feature	Source	Property
Flavonoids	Quercetin	$C_{15}H_{10}O_7$	C_6–C_3–C_6, poly hydroxylated	Onion, apple	Antioxidant
Phenolics	Gallic acid	$C_7H_6O_5$	Phenyl + OH, COOH	Tea, grapes	Antioxidant
Alkaloids	Caffeine	$C_8H_{10}N_4O_2$	Nitrogen-containing purine	Coffee	CNS stimulant

Conclusion

In this paper, a unified chemical graph theoretic framework has been developed to model and analyze the molecular structures of representative phytochemical compounds, namely Quercetin, Gallic acid, and Caffeine, belonging to the major classes of flavonoids, phenolic compounds, and alkaloids, respectively. By constructing hydrogen-suppressed molecular graphs, complex chemical structures were translated into mathematically tractable objects, enabling a rigorous investigation of their topological and spectral properties.

Adjacency, degree, Laplacian, distance, and distance Laplacian matrices were systematically derived for each molecular graph, and key invariants such as diameter, eccentricity, Wiener index, Laplacian energy, and distance Laplacian energy were examined. The presence of fused cycles, aromatic rings, and pendant oxygen or nitrogen vertices was shown to have a direct influence on connectivity, eccentricity distribution, and spectral characteristics. In particular, the connectivity of all considered molecular graphs was confirmed through Laplacian spectral properties, while pendant vertices were observed to attain maximum eccentricity, significantly contributing to distance-based descriptors.

The comparative analysis highlights that spectral graph invariants and energy measures effectively capture the underlying molecular complexity of phytochemical compounds. These descriptors provide quantitative insight into how structural variations among different phytochemical classes influence global topological behavior. The results demonstrate that chemical graph theory offers a powerful and unified mathematical approach for the structural characterization of phytochemicals and suggests potential applicability of spectral and distance-based indices in QSAR studies and rational drug design. Future work may extend this framework to larger classes of bioactive molecules and explore correlations between graph-theoretic invariants and experimentally observed physicochemical or biological properties.

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Original Article

Human-Centered Artificial Intelligence: Societal Transformation, Ethical Foundations, Regulatory Frameworks, and Educational Innovation

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Abstract

Artificial Intelligence (AI) has rapidly evolved from a specialized computational discipline into a pervasive socio-technical force shaping economies, governance systems, social interactions, and educational institutions. While AI-driven systems enhance productivity, decision-making, and personalization, they simultaneously introduce ethical dilemmas, regulatory challenges, and societal inequalities. This paper examines AI from a human-centered perspective, analyzing its transformative impact across four interrelated domains: society, ethics, governance, and education. The discussion highlights how AI reshapes labor markets, healthcare, communication ecosystems, and public services while raising concerns about algorithmic bias, privacy erosion, accountability, and digital exclusion. The study further explores emerging governance frameworks and regulatory approaches designed to ensure responsible AI development through transparency, fairness, and risk-based oversight. In the educational domain, AI-enabled personalization, intelligent tutoring systems, and learning analytics are evaluated for their pedagogical benefits and integrity challenges. The paper argues that sustainable AI integration requires a balanced alignment between innovation and ethical responsibility, supported by adaptive governance models and inclusive educational strategies. By synthesizing contemporary scholarly perspectives, this research contributes to ongoing debates on ensuring that AI development remains aligned with democratic values, human rights, and social well-being.

Keywords: *Artificial Intelligence, AI Ethics, AI Governance, Education Technology, Human-Centered AI*

Introduction

Artificial Intelligence (AI) refers to computational systems capable of performing tasks traditionally associated with human intelligence, including learning, reasoning, pattern recognition, and decision-making. In recent years, advances in machine learning, deep learning, and big data analytics have accelerated AI adoption across multiple sectors. AI technologies now influence healthcare diagnostics, financial systems, urban planning, law enforcement, media platforms, and education systems.

However, AI is not merely a technological development; it represents a socio-technical transformation. Its integration into social structures affects employment patterns, democratic processes, cultural interactions, and knowledge production. As AI systems become embedded in critical decision-making processes, concerns regarding fairness, accountability, transparency, and human autonomy have intensified. This paper examines AI from four interconnected dimensions: societal impact, ethical considerations, governance mechanisms, and educational transformation. By adopting a human-centered framework, the study emphasizes that AI development must prioritize social welfare, democratic values, and inclusive growth.

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AI in Society: Transformative Impacts

1. **Economic Restructuring and Labor Markets**
   AI-driven automation enhances efficiency in manufacturing, logistics, banking, and service industries. Routine and repetitive tasks are increasingly performed by intelligent systems, leading to productivity gains. However, automation also disrupts traditional employment structures. While certain roles decline, new professions in AI development, data science, cybersecurity, and digital ethics emerge.
   The challenge lies in managing workforce transitions through reskilling initiatives and lifelong learning frameworks. Without proactive policy intervention, AI adoption may widen income inequality and create structural unemployment.
2. **Healthcare and Public Welfare**
   AI supports predictive diagnostics, medical imaging analysis, robotic-assisted surgery, and personalized treatment planning. Machine learning models improve early disease detection and healthcare resource allocation. During public health crises, AI tools assist in data modeling and outbreak prediction.
   Nevertheless, reliance on AI in healthcare raises concerns regarding data privacy, algorithmic transparency, and accountability in case of diagnostic errors.
3. **Digital Communication and Social Media**
   AI algorithms curate online content, moderate harmful speech, and personalize user experiences. While personalization enhances engagement, it may also create echo chambers and reinforce misinformation. Deepfake technologies further complicate digital trust, threatening democratic processes and social cohesion.
4. **Social Inequality and the Digital Divide**
   Access to AI technologies remains uneven across regions and socioeconomic groups. Developing countries face infrastructural and financial constraints, limiting participation in AI-driven economic growth. Ethical AI development must therefore incorporate inclusivity and equitable access.

Ethical Foundations of Artificial Intelligence

AI ethics seeks to ensure that technological advancement aligns with moral principles and human rights.

1. **Algorithmic Bias and Fairness**
   AI systems trained on biased datasets may perpetuate discrimination in hiring, lending, healthcare, and criminal justice. Ensuring fairness requires representative datasets, bias audits, and continuous monitoring.
2. **Privacy and Data Protection**
   AI systems rely on vast volumes of personal data. Surveillance technologies and facial recognition systems raise concerns regarding consent and individual autonomy. Data minimization and privacy-by-design principles are essential safeguards.
3. **Transparency and Explainability**
   Many AI systems operate as "black boxes," making their decision processes difficult to interpret. Explainable AI (XAI) aims to improve interpretability, especially in high-risk domains such as healthcare and finance.
4. **Accountability and Responsibility**
   Determining responsibility when AI systems cause harm remains complex. Ethical governance demands clear accountability structures involving developers, deployers, and regulators.
5. **Human Autonomy**
   AI systems should augment rather than replace human judgment in critical domains. Maintaining meaningful human oversight preserves moral agency and democratic control.

AI Governance: Regulatory and Policy Frameworks

Effective governance ensures that AI innovation proceeds within socially acceptable boundaries.

1. **Risk-Based Regulatory Approaches**
   Governments increasingly adopt risk-tiered regulatory models, where high-risk applications such as biometric surveillance or medical diagnostics face stricter oversight. This approach balances innovation with protection.
2. **International Policy Initiatives**
   Global organizations have proposed ethical AI guidelines emphasizing transparency, fairness, and human rights. International collaboration is essential to manage cross-border data flows and prevent regulatory fragmentation.
3. **Institutional Oversight Mechanisms**
   Ethics committees, audit boards, and regulatory authorities monitor AI compliance. Public-private partnerships also play a role in shaping standards.
4. **Challenges in Governance**
   Rapid technological evolution often outpaces legal adaptation. Moreover, geopolitical competition influences AI policy decisions, complicating global cooperation.
   Governance must therefore remain flexible, adaptive, and participatory.

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AI in Education: Opportunities and Challenges

1. **Personalized Learning**
   Adaptive learning systems tailor instructional content to individual student needs. AI-powered platforms analyze performance data to recommend customized learning pathways.
2. **Intelligent Tutoring Systems**
   Virtual tutors provide real-time feedback and 24/7 academic assistance. Such systems enhance accessibility, particularly for remote and underserved learners.
3. **Automated Assessment**
   AI enables rapid grading of objective assessments and supports formative feedback. However, concerns arise regarding accuracy, bias, and academic integrity.
4. **Learning Analytics**
   Data-driven insights assist educators in identifying at-risk students and improving curriculum design. Nevertheless, excessive surveillance may infringe on student privacy.
5. **Ethical and Pedagogical Considerations**
   Overreliance on AI tools may weaken critical thinking and originality. Educational institutions must integrate digital literacy, AI awareness, and ethical reasoning into curricula.

Toward Human-Centered AI Integration

A sustainable AI ecosystem requires:

- Ethical-by-design development
- Transparent and explainable systems
- Inclusive access to AI benefits
- Adaptive governance frameworks
- AI literacy education

Collaboration among technologists, policymakers, educators, and civil society is essential for aligning AI innovation with human values.

Conclusion

Artificial Intelligence represents a transformative force reshaping society, governance, ethics, and education. While AI enhances efficiency, personalization, and predictive capabilities, it simultaneously introduces risks related to bias, privacy, inequality, and accountability. Responsible AI integration demands a human-centered approach grounded in ethical principles, regulatory oversight, and inclusive educational strategies.

Future research should focus on interdisciplinary models that integrate technical innovation with social sciences and humanities perspectives. By ensuring transparency, fairness, and democratic participation, AI can serve as a catalyst for sustainable and equitable global development.

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Original Article

Synthesis of Novel Benzoxazole Derivatives and Study of their Anticancer Activity

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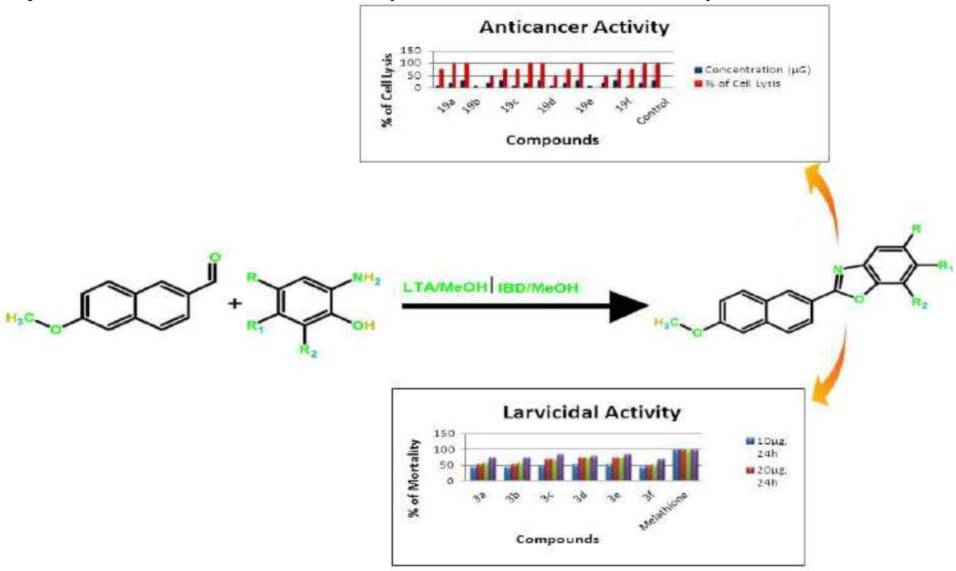
Abstract

The cyclization of Schiff's bases 2-(6-methoxy-2-naphthyl) methylene] amino} phenol derivatives using Iodobenzoxydi acetate (IBD)/Lead tetra acetate (LTA) to yield 2-(6-methoxy-2-napthyl)-1,3-benzoxazole derivatives ***3a-f*** *is achieved. IBD is the most efficient and effective and acts as oxidant in the synthesis of target molecules with better yield than LTA. The obtained products have been characterized by IR, ^{1}H NMR, ^{13}C NMR and Mass spectral studies. The anticancer activity revealed that the compounds* ***3a, 3c, 3d*** *and* ***3f*** *were the most active compounds in the series towards HT-29- Human colorectal adenocarcinoma cell line by total lysis with minimum concentration and supported by in silico molecular docking studies.*

Keywords: *Benzoxazole, Iodobenzoxydiacetate, Anticancer Activity.*



Introduction

The oxazole containing heterocyclic compounds plays an imperative role in medicinal chemistry and exhibit wide range of biological activities. Five-membered heterocyclic rings, such as benzoxazoles, benzothiazoles, and benzimidazoles, are present in natural products, and in synthetic pharmaceutical and agrochemical compounds [1].

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These compounds have been extensively studied for their biological and therapeutic activities, such as acathepsin S inhibitor [2], a HIV reverse transcriptase inhibitor [3], an anticancer agent [4] and an orexin-1 receptorantagonist [5]. The benzoxazoles have been in the focus line for the researchers from many years due to imported as class of heterocyclic compounds [6]. Especially 2-substituted benzoxazoles were prominently studied trusting thatthis position is influential for the biological activity whereas position 5 existing the intensity ofactivity. The oxidative intramolecular cyclization of phenolicSchiff base is well known method and the oxidants have an effect on yield in oxidative ring-closure reactions. Some reagents have been used for oxidative cyclization of Schiff bases, including lead tetraacetate. Because of the low toxicity, ready availability and easy handling and good yield, the organo hypervalent iodine reagents [7] such as iodobenzenediacetate (IBD) [8] have been broadly used in organic synthesis. In connection with our recent interest in catalyzedC-C bond formation, we envisioned that by the addition of the *o*-hydroxy phenol to the Schiff base, which generated in situ from the condensation of Substituted 2-aminophenol with 6-methoxy napthaldehyde, the Schiff base could be further oxidized intosubstituted benzoxazole in situ under air or oxygen atmosphere withIBD and LTA catalyst.The LTA is used one of the oxidant commonly; however, it has found that LTA is not suitable for preparation of target molecules due to the low yield factor [9].

According to the IndianCancer Society, about 1.5 million people suffer from cancer at any point of time in India. At present scenario, development of drugswith target specific predefined anticancer potential is moreessential to fight against various types of cancers. Recently, the EGFR inhibitory activity has been hypothesized to possesstherapeutic potential for treatment of cancer. So, there is aneed for rapid and efficient computational methods capable ofdifferentiating compounds with acceptable biopharmaceuticalproperties [10]. In the present study, we have synthesized novel 2-substituted benzoxazoles using both IBD and LTA as oxidants, comparing the yield and duration for completion of reaction and subjected to anticancer and larvicidal activities to discern the potentiality of the synthesized compounds.

Materials and Methods

1. **Chemistry**

   Melting points were recorded on electro-thermal melting point apparatus and are uncorrected. ^{1}H NMR and ^{13}C NMR spectra were recorded on Bruker 400 MHz spectrometer in IISc, Bangalore, Karnataka, India. The chemical shifts are shown in δ values (ppm) with tetramethylsilane (TMS) as an internal standard. LC-MS were obtained using C 18 column on Shimadzu, LCMS 2010A, Japan. The FT-IR spectra of the compounds were taken in KBr pellet (100 mg) using Shimadzu Fourier Transformed Infrared (FT-IR) Spectrophotometer.

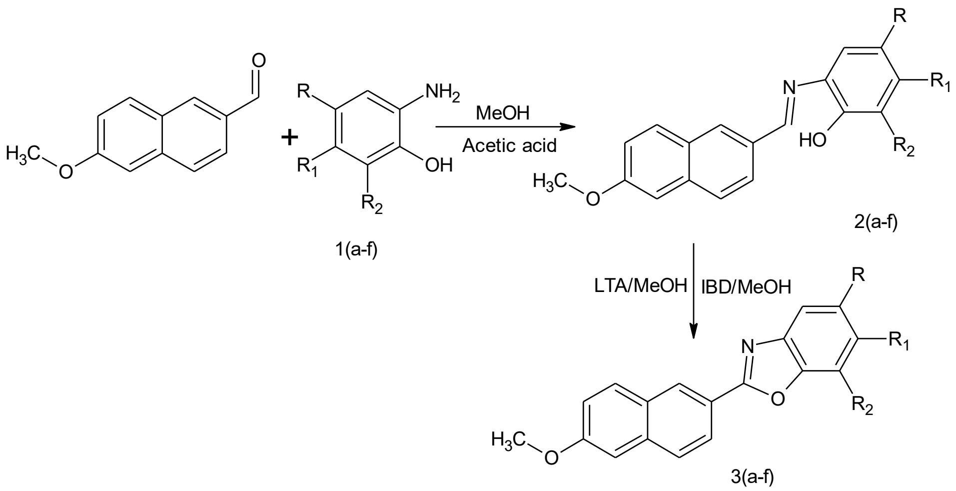
2. **General procedure for the synthesis of 2-(6-methoxy-2-naphthy l) methylene] amino} phenol derivatives 2a**

   6-Methoxy-2-napthaldehyde (0.01 mol) amino phenols **1a** (0.01 mol) and catalytic amount of acetic acid were taken in methanol and refluxed for 5 h. The completion of the reaction was monitored by TLC. Then the reaction mass was cooled and filtered to get solid products **2a**. The compounds **2a-f** were synthesized by same method

3. **General procedure for the synthesis of 2-(6-methoxy-2-napthyl)-1,3-benzoxazole derivatives 3a**

   Method A: Compounds **2a** (0.01 mol) and Iodobenzoxydiacetate (0.01 mol) were taken in methanol and stirred at room temperature for 2h. The progress of reaction was monitored by TLC. The reaction mass was filtered to get the compounds **3a**. The compounds **3a-f**weresynthesized by same method.

   Method B: Compounds **2a** (0.01 mol) and Lead tetraacetate (0.01 mol) were taken in methanol and stirred at room temperature for 4 h. The progress of reaction was monitored by TLC. The reaction mass was filtered to get the compounds **3a**. The compounds **3a-f** were synthesized by same method and represented in Fig 1.



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4. Spectral data:

2-(6-methoxy-2-naphthyl)-1,3-benzoxazole (3a). Anal. Calcd for (%) $C_{18}H_{13}NO_2$(275.3 gm/mole):C 78.53, H4.76, N5.09,Found: C78.52, H4.75, N 5.10;IR (KBr) cm^{-1}: 3013 (OCH_3), 1471 (C=C); ^{1}H NMR (DMSO-*d6*) ppm: □3.91 (s, 3H, OCH_3), □ 7.2-8.2 (10H, Ar H);^{13}CNMR (DMSO-*d6*):164.10, 158.49, 149.05, 142.32, 136.41, 135.0, 130.96, 128.47, 128.26, 128.04, 126.99, 125.56, 122.93, 121.20, 119.93, 110.61, 107.02 (17 Ar-C), 55.90 (methoxy);M276.1.

2-(6-methoxy-2-naphthyl)-5-methyl-1,3-benzoxazole (3b). Anal. Calcd for (%) $C_{19}H_{15}NO_2$(289.32 gm/mole):C78.87, H5.23, N4.84,Found: C78.88, H5.24, N4.82;IR (KBr) cm^{-1}: 3116 (CH3), 3013 (OCH_3), 1480 (C=C); ^{1}H NMR (DMSO-*d6*) ppm: □ 2.4 (s, 3H, CH_3), □3.91 (s, 3H, OCH_3), □ 7.2-8.7 (9H, Ar H);^{13}CNMR (DMSO-*d6*):163.21, 159.44, 148.97, 142.39, 136.47, 134.67, 131.07, 128.43, 128.22, 127.96, 126.76, 124.57, 121.96, 120.22, 119.94, 110.65, 106.70 (17 Ar-C), 55.89 (methoxy), 21.48 (methyl);*M*290.2.

5-chloro-2-(6-methoxy-2-naphthyl)-1,3-benzoxazole (3c). Anal. Calcd for (%) $C_{18}H_{12}ClNO_2$(309.74 gm/mole):C69.80, H3.90, N4.52 Found: C69.82, H3.89, N4.51;IR (KBr) cm^{-1}: 3086 (OCH_3), 1480 (C=C)773 (C-Cl); ^{1}H NMR (DMSO-*d6*) ppm: □3.92 (s, 3H, OCH_3), □ 7.27-8.75 (9H, Ar H);^{13}CNMR (DMSO-*d6*):164.67, 159.65, 149.55, 143.50, 136.74, 131.18, 129.48, 128.49, 128.32, 125.76, 124.56, 121.33, 120.32, 119.79, 112.62, 106.72, (17 Ar-C), 55.92 (methoxy);*M*310, M^{+2} 311.

5,7-dichloro-2-(6-methoxy-2-naphthyl)-1,3-benzoxazole (3d). Anal. Calcd for (%) $C_{18}H_{11}Cl_2NO_2$(344.19 gm/mole):C62.81, H3.22, N4.07Found: C62.83, H3.86, N4.53;IR (KBr) cm^{-1}: 3020 (OCH_3), 1463 (C=C)775 (C-Cl); ^{1}H NMR (DMSO-*d6*) ppm: □3.92 (s, 3H, OCH_3), □ 7.27-8.75 (8H, Ar H);^{13}CNMR (DMSO-*d6*):164.65, 159.61, 149.53, 143.480, 136.72, 130.78, 129.44, 128.43, 128.31, 125.71, 124.52, 121.35, 120.31, 119.78, 112.61, 106.74, (17 Ar-C), 55.91 (methoxy);*M/z* 344.2,M^{+2} 346, M^{+4} 348.

2-(6-methoxy-2-naphthyl)-5-nitro-1,3-benzoxazole (3e). Anal. Calcd for (%) $C_{18}H_{12}N_2O_4$(320.29 gm/mole):C67.50, H3.78, N8.75 Found: C67.10, H3.8, N8.77;IR (KBr) cm^{-1}: 3011 (OCH_3), 1551 (-NO_2), 1471 (C=C); ^{1}H NMR (DMSO-*d6*) ppm: □3.91 (s, 3H, OCH_3), □ 7.25-8.71 (9H, Ar H);^{13}CNMR (DMSO-*d6*):163.23, 159.42, 148.95, 142.36, 136.45, 134.65, 131.06, 128.42, 128.21, 127.94, 126.76, 124.56, 121.98, 120.20, 119.95, 110.67, 106.72 (17 Ar-C), 55.88 (methoxy);*M/z* 320.

2-(6-methoxy-2-naphthyl)-6-nitro-1,3-benzoxazole (3f). Anal. Calcd for (%) $C_{18}H_{12}N_2O_4$(320.29 gm/mole):C67.50, H3.78, N8.75 Found: C67.10, H3.8, N8.77;IR (KBr) cm^{-1}: 3015 (OCH_3), 1598 (-NO_2), 1474 (C=C); ^{1}H NMR (DMSO-*d6*) ppm: □3.92 (s, 3H, OCH_3), □ 7.24-8.74 (9H, Ar H);^{13}CNMR (DMSO-*d6*):163.22, 159.41, 148.93, 142.34, 136.44, 134.63, 131.07, 128.43, 128.22, 127.96, 126.77, 124.58, 121.96, 120.23, 119.93, 110.64, 106.70 (17 Ar-C), 55.87 (methoxy);*M/z* 320.

Results and Discussion

Chemistry

The 6-methoxy-2-napthaldehyde condensed with different o-amino phenols formed corresponding Schiff's bases. The Schiff bases were cyclized by using lead tetraacetate and iodobenzoxydiacetate separately (**Scheme-1**). The difference in the percentage of yield and time taken for the completion of reaction using both reagentswas observed (**Table 1**). The lead tetraacetate products were obtained in low yield as compared to the yield obtained by using iodobenzoxydiacetate. Nearly 20% of yield difference was observed and the reaction completed within 2h, when IBD catalyst used and it takes more time (4h) in LTA. The purity of the compounds waschecked by TLC. Spectral data of the newly synthesized compounds **3a-f**were in full accordance with their proposed structures. The absence of stretching frequency for C=O group in IR spectrum and absence of aldehydic proton of 6-methoxy-2-napthaldehyde at □□□□□value□and□achieve new peak for -N=CH proton in ^{1}H NMR confirmed the formation of Schiff bases. The cyclization of compounds **2a-f**with ease of the reaction by stirring the reaction mass i.e Schiff bases **2a-f**with catalyst in methanol at room temperature achieved. Here both -N=CH and –OH protons disappearedand gives the cyclized benzoxazole moiety. The characterizations of the final molecules **3a-f** werebasedon the careful comparison of IR, ^{1}H NMR,^{13}CNMRand mass spectral data and represented in supplementary file S1 to S8. The physicochemical parameters of the synthesized compounds were mentioned in **Table 1.**

Table 1: Physical data of compounds 3(a-f)

Compounds	Molecular Formula	Molecular Weight	M.P.(°C)	Yield (%) Lead tetraacetate	Iodobenzoxy diacetate
3a	$C_{18}H_{13}NO_2$	275.3	143-144	65	73
3b	$C_{19}H_{15}NO_2$	289.3	130-131	63	77
3c	$C_{18}H_{12}ClNO_2$	309.7	160-161	68	78
3d	$C_{18}H_{11}Cl_2NO_2$	344.2	203-204	65	74
3e	$C_{18}H_{12}N_2O_4$	320.3	167-168	61	71
3f	$C_{18}H_{12}N_2O_4$	320.3	171-172	64	73

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Biological Evaluation

Anticancer activity

Cell Lines and Cell Culture: Cell line-HT-29 -Human colorectal adenocarcinoma are obtained from Maratha Mandal Dental College, Belgaum, Karnataka. Human colon cancer cell (HT-29) lines were maintained in MEM medium. The media were supplemented with 10% (v/v) heat-inactivated fetal bovine serum, 100 U/mL penicillin and 100 µg/mL streptomycin. Cells were cultured in a humidified atmosphere and incubated at 37°C in 5% CO_2.

Cytotoxicity and Anti-Proliferation Test: Human colon cancer cell (HT-29) cell line was used as normal cell control for this study [15]. This cell line belongs to Human adenocarcinoma colorectal cells. HT-29 cell lines were seeded in 96-well plates (1 × 105 cells/well) and incubated in DMEM, at 37°C in 5% CO_2 for 24 hrs. The cells were pretreated with 10, 20, and 30 µg/mL of each compound for 24 hrs and incubated in RPMI 1640, at 37°C in humidified atmosphere of 5% CO_2 for 72 h. After 4 h of incubation, the supernatant solution was discarded and 200 µL of DMSO was added to each well to terminate the reaction. The absorbance was measured at 550 nm using an enzyme-linked immunosorbent assay (ELISA) plate reader (Bio-Tek, Winooski, VT, USA). For the treated cells, viability is expressed as the percentage of control cells.

The compounds **3a**, **3c**, **3d** and **3f** from the series showed potent anticancer activity towards Human colon cancer cell (HT-29). Even at low concentration i.e10 µGmore than 75% of cells were destroyed and in some cases 100% lysis observed for same concentration. Only compounds **3b** and **3e** were marked no lysis at concentration i.e10 µG, but possess moderate activity at slightly higher concentration. The results were tabulated in the **Table-2 (Fig.5)**. The study further strengthened by the molecular docking analysis. The binding energies of the active molecules greater for the active compounds **3a**, **3c**, **3d** and **3f**.

Table-2: Anticancer activity of the compound 19c

Compound	Concentration (µg)	O.D. at 492nm	%of cell lysis	IC_{50}
19c	10	1.159	>75%lyses	<10 µg
	20	1.461	**100% lyses**	
	30	1.444	**100% lyses**	
Control	-	0.505	No lyses	-

Conclusion

The synthesis of benzoxazole moiety with the ease and procedural simplicity are the key aspects of the synthesis. The synthesis of 2-(6-methoxy-2-napthyl)-1,3-benzoxazole derivatives have been achieved easily via iodobenzoxy diacetate and lead tetraacetate. It was observed that, the iodobenzoxy diacetate was the effective catalyst and acted as good oxidant than lead tetraacetate in good yield at lesser time. The result of the anticancer screening revealed that, among the title compounds, the compounds **3a**, **3c** and **3d** and **3f** showed greater cell lysis while the other compounds displayed moderate lysis towards Human colon cancer cell (HT-29) lines. Considering all the data, the iodobenzoxy diacetate is the effective oxidant in the cyclization of Schiff base than lead tetra acetate and some compounds from the series emerges as potent biologically active molecules.

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Original Article

k-Square Difference Mean Labeling for Some Graphs

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Abstract

k-square difference mean labeling of a graph $G = (p, q)$ *with* p *vertices and edges* q *if there exists a bijection* $f : p(G) \rightarrow \{k-1,\ k,\ k+1,\ k+2,\ k+3, k+4, \ldots, (p-2)\}$ *such that the induced function* $f^* : q(G) \rightarrow N$ *given by function* $f^*(u, v) = \left\lceil \frac{f(u)^2 - f(v)^2}{2} \right\rceil$ or $f^*(u, v) = \left\lfloor \frac{f(u)^2 - f(v)^2}{2} \right\rfloor$ *are injective the resulting edge labels being distinct. Square sum labeling was introduced by K. Ajitha, S. Arumugam and K.A. Germina. Square difference labeling was introduced by J. Shiama. Mean labeling was introduced by S. Somasundaram and R. Ponraj. Further, it was studied by B. Gayathri and R. Gopi. B. Gayathri, R. Thayalarajan introduced k-square difference mean labeling in this paper, we investigate the k-square difference mean labeling graph thorn ring, wheel graph* (w_n).

Keywords: *Graph, Graph labeling, k-square difference mean labeling (k-SDML), thorn ring, wheel graph* (w_n).
AMS Subject Classification -05C78

Introduction

The field of Graph Theory plays an important role in various areas of pure and applied sciences. Graph Labeling of a graph G is an assignment of integers either to the vertices or edges or both subject to certain conditions. Graph labeling is a very powerful tool that eventually makes things in different fields very ease to be handled in mathematical way. Nowadays graph labeling has much attention from different brilliant researches in graph theory which has rigorous applications in many disciplines, e.g., communication networks, coding theory, optimal circuits layouts, astronomy, radar and graph decomposition problems Detailed survey on graph labeling is given and up dated by Gallian[3].

All graphs are in this paper are simple, connected, finite, undirected graph $G = (p(G), q(G))$ with $p = |p(G)|$ and $q = |q(G)|$. The symbol $p(G)$ and $q(G)$ denote vertex sett of G and edge set of G the terminology and notations we follow Frank Harary [2].

Square sum labeling was introduced by K. Ajitha, S. Arumugam and K.A. Germina [1]. Square difference labeling was introduced by J. Shiama [7]. Mean labeling was introduced by S. Somasundaram and R. Ponraj [8]. (k, d) −super root square mean labeling of graphs was extend this notion by B. Gayathri and R. Thayalarajan [3]. Further, it was studied by B. Gayathri and R. Gopi. k-square difference mean labeling of graphs was introduced by B. Gayathri and R. Thayalarajan [4]

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Definitions

Definition 2.1. Graph labeling: A graph labeling is an assignment of integers to the vertices or edges or both subject to certain conditions. Graph labeling was introduced in the late 1960s. For a detailed survey on graph labeling we refer to Gallian [3].

Definition 2.2. k-square difference mean graph : A graph $G = (p, q)$ k-square difference mean labeling (k-SDML) if there exists a bijection $f : p(G) \to \{k-1,\ k,\ k+1,\ k+2,\ \ldots,(p-2)\}$ such that the induced function $f^* : q(G) \to N$ given by function $f^*(u,v) = \left\lceil \frac{f(u)^2 - f(v)^2}{2} \right\rceil$ or $f^*(u,v) = \left\lfloor \frac{f(u)^2 - f(v)^2}{2} \right\rfloor$ is injective the resulting edge labels are distinct. A graph G which admits a k-square difference mean labeling is called k-square difference mean graph.

Definition 2.3. Thorny ring: A thorn ring has a simple cycle as the parent and t-2 thorns at each cycle vertex. It is denoted by $(C_{p,t})$

Definition 2.4. Wheel graph: The wheel graph w_n is defined to be the join of K_1 and C_n ie the wheel graph consists of edges which joins a vertex of K_1 to every vertex of C_n

Main Results:

Theorem 3.1: *The thorny ring* $(C_{p,t})$ *is an k-square difference mean graph if* $'p'$ *is odd for all* $k \geq 2,\ t \geq 3.$

Proof: The thorny ring graph has order $'n'$ and size $'m'$. If f is a k-square difference mean labeling of G, f assigns the labels $k-1,\ k,\ k+1,\ k+2,\ \ldots,(p-2)$ on the n vertices of $G.$

Now label the assigned to the vertices as defined below.

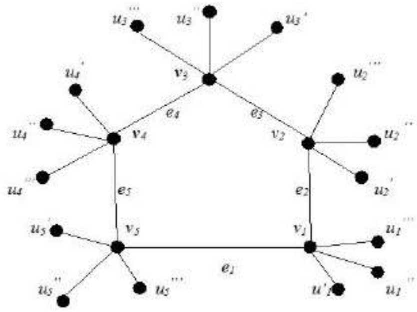

Fig.1

$$f(v_i) = \begin{cases} i+1 & where\ \ i = 3,5,7 \ldots\ldots\ldots p \\ i+1 & where\ \ i = 2,4,6 \ldots\ldots\ldots p-1 \\ \dfrac{p-1}{\dfrac{p-1}{2}} & where\ \ i = 1 \end{cases}$$

$f(u_i') = \frac{2\,(p-1)+2}{2} + j$ $\quad$ *where* $2 \leq j \geq p\ and\ \ 1 \leq i \geq p$

$f(u_i'') = 2\left[\frac{2\,(p-1)+2}{2} + j\right]$ $\quad$ *where* $2 \leq j \geq p\ and\ \ 1 \leq i \geq p$

$f(u_i''') = 3\left[\frac{2\,(p-1)+2}{2} + j\right]$ $\quad$ *where* $2 \leq j \geq p\ and\ \ 1 \leq i \geq p$

:

:

$f(u_i^{\propto}) = \propto \left[\frac{2\,(p-1)+2}{2} + j\right]$ $\quad$ *for* $2 \leq j \geq p\ and\ 1 \leq i \geq p$ where $\propto = t-2.$

Now edge labeling function is defined as $f^*(u,v) = \left\lceil \frac{f(u)^2 - f(v)^2}{2} \right\rceil$ or $f^*(u,v) = \left\lfloor \frac{f(u)^2 - f(v)^2}{2} \right\rfloor$

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By calculating the labels it can be seen that the above function induced all of the cycle even edge labels from $k-1$ to $2k-2$ when $1 \leq i \geq p-2$. When i is odd, the edge labels e_i i.e $[e_1\, e_3\, e_5 \ldots\ldots (p-2)]$ values that start at $k-1$ and increases by 2 i increases 2 until $i = \frac{2p}{2} - 2$. When i even the edge label from k to p when $1 \leq i \geq p-1$. When i even the edge label e_i i.e $[e_2\, e_4\, e_6 \ldots\ldots (p-1)]$ values that start at 1 and increases by 2 as i increases by 2 until $i = \frac{2p}{2} - 1$. Which always produced the edge label is p. Now the function changes at $i = \frac{2p+2}{2} - 1$ induced edge label is $\frac{(p+1)^2-(k-1)^2}{2}$ this edge label is highest value in cycle (c_n) and label the function $f(u_i')$ start edge label values at $\frac{(k)^2-(p+2)^2}{2}$ and remaining edge function values so we will get without any vertex or edge label repeated so the thorny ring ($C_{p,\ t}$) is an k-square difference mean graph if $'p'$ is odd.

Theorem 3.2: *The wheel graph (w_n) is an k-square difference mean graph if for al lk* ≥ 2.

Proof: The wheel graph (w_n) has order $'n'$ and size $'2(n-1)'$. If f is a k-square difference mean labeling of G, f assigns the labels $k-1,\ ,\ k+1,\ k+2,\ \ldots,(p-2)$ on the n vertices of G. Now label the assigned to the vertices as defined below.

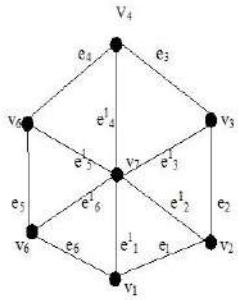

Fig.2

$$f(v_{1+2i}) = 2i+1 \qquad where \quad i = 0,1,2 \ldots\ldots \frac{n-1}{2} \quad when \ n \ is \ odd$$

$$f(v_{1+2i}) = 2i+1 \qquad where \quad i = 0,1,2 \ldots\ldots n-1 \quad when \ n \ is \ even$$

$$f(v_{2i}) = 2i \qquad where \quad i = 1,2 \ldots\ldots n-2 \quad when \ n \ is \ odd$$

$$f(v_{2i}) = 2i \qquad where \quad i = 1,2 \ldots\ldots \frac{n}{2} \quad when \ n \ is \ even$$

Now edge labeling function is defined as $f^*(u,v) = \left\lceil \frac{f(u)^2 - f(v)^2}{2} \right\rceil$ or $f^*(u,v) = \left\lfloor \frac{f(u)^2 - f(v)^2}{2} \right\rfloor$ if n is odd by calculating the labels it can be seen that the above function induced all of the cycle odd edge labels from $k-1$ to $\frac{n}{2} - 1$, When i is odd, the edge labels e_i i.e $\left[e_1\, e_3\, e_5 \ldots\ldots \left(\frac{n}{2} - 1\right)\right]$ values that start at $k-1$ and increases by 2 as i increases 2 until $i = \frac{n}{2} - 1$. then $k-1$ to $\frac{n}{2} - 1$. if n is even induced all of the cycle odd edge labels from $k-1$ to $\frac{n}{2} - 1$, When i is odd, the edge labels e_i i.e $\left[e_2\, e_4\, e_6 \ldots\ldots \left(\frac{n-1}{2}\right)\right]$ values that start at $k-1$ and increases by 2 as i increases 2 until $i = \frac{n}{2} - 1$. When i even the edge label from k to $n-2$, where n is even, When i even the edge label e_i i.e $[e_2\, e_4\, e_6 \ldots\ldots (n-2)]$ values that start at k and increases by 2 as i increases by 2 until $i = n-2$. Which always produced the edge label is $n-2$. When i even the edge label from k to $n-3$ where n is odd, When i even the edge label e_i i.e $[e_2\, e_4\, e_6 \ldots\ldots (n-3)]$ values that start at k and increases by 2 as i increases by 2 until $i = n-2$. Which always produced the edge label is $n-2$. Now the function changes at $i = \frac{2n+2}{2} - 2$ induced edge label is $\frac{(n-1)^2-(k-1)^2}{2}$ this edge label is highest value in odd cycle (c_n) and in even cycle the function changes at $i = \frac{2n+2}{2} - 2$ induced edge label is $\frac{(n-1)^2 - (k-1)^2}{2}$ this edge label is highest value in even cycle (c_n) .continue the remaining edge function values so we will get without any vertex or edge label repeated so the wheel graph (w_n) is a k-square difference mean graph.

Conclusion: lastly, we conclude that the thorny ring ($C_{p,t}$) graph, wheel graph (w_n) is a k-square difference mean graph are investigated it can moreover be verified for several other graph**s.**

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Original Article

Water Quality in India: Status, Challenges, and Solutions

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Abstract

Water quality in India is a major environmental and public health concern due to rapid urbanization, industrialization, and population growth. This research article reviews the current status of water quality across different regions, identifies major pollutants and sources, and discusses impacts on human health and ecosystems. Using secondary data from government reports and scientific studies, this paper analyses water quality indicators like pH, dissolved oxygen (DO), biological oxygen demand (BOD), chemical oxygen demand (COD), heavy metals, and microbial contamination. Results show that many water bodies in India fail to meet national and international standards, largely due to untreated sewage discharge, industrial effluents, and agricultural runoff. The paper concludes with policy recommendations to improve water quality management.

Introduction

Water is essential for life, agriculture, industry, and ecosystems. India, with its diverse geography and large population, faces significant challenges in ensuring access to safe and clean water. Despite abundant freshwater resources, the quality of water in rivers, lakes, and groundwater is deteriorating. Contaminated water increases the risk of waterborne diseases, damages aquatic life, and affects socio-economic development. This study aims to assess the current water quality status in India, identify key pollution sources, and recommend strategies for improvement.

Review of Literature

1. **Water Quality Assessment in Rivers:** Many studies have documented pollution in major rivers like the Ganges, Yamuna, and Cauvery. For example, research by Kumar et al. (2019) found high levels of BOD, COD, and coliform bacteria in the Yamuna near Delhi due to untreated sewage discharge.
2. **Groundwater Contamination:** Groundwater in states like Punjab and Rajasthan shows elevated levels of nitrates and fluoride, largely from fertilizers and geogenic sources (Sharma & Singh, 2018).
3. **Impact on Health:** Studies also link contaminated water with diseases. A study by Singh (2020) estimated that waterborne diseases contribute significantly to morbidity, especially among children in rural India.
4. **Government Policies:** The National Water Policy and initiatives like the Jal Shakti Mission aim to improve water quality through wastewater treatment and pollution control measures, though implementation remains a challenge (MoEFCC Report, 2022).

Materials and Methodology

Data Collection

This study uses **secondary data** from:

- Central Pollution Control Board (CPCB)
- National Institute of Hydrology

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- Scientific journals and environmental reports
- Government policy documents

Water Quality Indicators Used

- **pH:** Indicates acidity or alkalinity of water.
- **Dissolved Oxygen (DO):** Shows oxygen available for aquatic life.
- **Biological Oxygen Demand (BOD) & Chemical Oxygen Demand (COD):** Measures organic pollution.
- **Total Coliforms:** Indicates microbial contamination.
- **Heavy Metals (Lead, Mercury, Arsenic):** Shows industrial pollution.

Analytical Approach

1. Compilation of data from reports published in the last 10 years (2014–2024)
2. Comparison with **Bureau of Indian Standards (BIS)** and **World Health Organization (WHO)** water quality guidelines
3. Qualitative synthesis of findings to identify major trends

Results and Discussion

Status of Water Quality

- **Surface Water:** Many rivers stretch fail to meet standards for DO, BOD, and coliform counts. For example, parts of the Ganges show DO levels below the safe limit and extremely high coliform counts.
- **Groundwater:** Elevated nitrates and heavy metals like arsenic and fluoride were found in states such as Bihar, West Bengal, and Rajasthan above permissible limits.
- **Urban vs Rural:** Urban water bodies are more affected by industrial effluents and domestic sewage, while rural areas suffer from agricultural runoff and inadequate sanitation infrastructure.

Causes of Pollution

1. **Untreated Sewage:** A major contributor in urban areas.
2. **Industrial Effluents:** Discharge of chemicals and heavy metals.
3. **Agricultural Runoff:** Use of fertilizers and pesticides raises nitrate levels in water.
4. **Lack of Infrastructure:** Inadequate wastewater treatment facilities.

Impacts on Health and Environment

- Increased waterborne diseases such as diarrhea, cholera, and dysentery.
- Harm to aquatic ecosystems due to low oxygen levels and toxic pollutants.

Policy and Management Challenges

- Gaps in implementation of environmental regulations.
- Limited monitoring in rural and remote areas.
- Need for community participation in water conservation.

Table 1: Major Water Quality Parameters and Standards

Parameter	Acceptable Limit (BIS/WHO)	Significance
pH	6.5 – 8.5	Indicates acidity/alkalinity
Dissolved Oxygen (DO)	≥ 5 mg/L	Essential for aquatic life
Biological Oxygen Demand (BOD)	≤ 3 mg/L	Indicates organic pollution
Chemical Oxygen Demand (COD)	≤ 250 mg/L	Measures chemical pollutants
Total Coliform	0 per 100 ml	Indicates microbial contamination
Nitrate (NO_3^-)	≤ 45 mg/L	Excess causes health issues
Fluoride (F^-)	≤ 1.5 mg/L	Excess causes fluorosis

Table 2: Water Quality Status of Major Indian Rivers

River	Location	BOD (mg/L)	DO (mg/L)	Coliform Count	Water Quality Status
Ganga	Varanasi	4.5	4.2	Very High	Polluted
Yamuna	Delhi	8.0	2.1	Extremely High	Severely Polluted
Cauvery	Tamil Nadu	3.8	4.8	High	Moderately Polluted
Godavari	Maharashtra	2.9	5.6	Moderate	Slightly Polluted
Narmada	MP	2.1	6.2	Low	Acceptable

Table 3: Groundwater Contamination in Selected States

State	Major Contaminant	Observed Value	Permissible Limit	Source
Bihar	Arsenic	0.08 mg/L	0.01 mg/L	Geogenic
Rajasthan	Fluoride	3.2 mg/L	1.5 mg/L	Natural
Punjab	Nitrate	75 mg/L	45 mg/L	Fertilizers
West Bengal	Arsenic	0.05 mg/L	0.01 mg/L	Sedimentary rocks
Karnataka	Nitrate	60 mg/L	45 mg/L	Agriculture

Table 4: Major Sources of Water Pollution in India

Source	Type of Pollution	Impact
Domestic Sewage	Organic & microbial	Waterborne diseases
Industrial Effluents	Heavy metals, chemicals	Toxicity to life
Agricultural Runoff	Nitrates, pesticides	Eutrophication
Solid Waste Dumping	Physical & chemical	Ecosystem damage

Table 5: Health Impacts Due to Poor Water Quality

Contaminant	Disease/Effect
Coliform bacteria	Diarrhea, Cholera
Arsenic	Skin lesions, Cancer
Fluoride	Dental & skeletal fluorosis
Nitrate	Blue baby syndrome
Heavy metals	Organ damage

Conclusion

Water quality in India remains a pressing issue with serious implications for public health and sustainable development. Although government policies exist to tackle water pollution, effective implementation and infrastructure development are crucial. Improving wastewater treatment, enforcing pollution control laws, and promoting community involvement can collectively enhance water quality.

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Original Article

Study on Synthesis, Characterisation and Biological screening of 5-bromo-7- methoxy-2-heterocycle substituted Benzofuran derivatives

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Abstract

Owing to the broad spectrum of biological properties of benzofuran nucleus linked with various five and six membered heterocyclic rings, we now undertake the synthesis of 5-Bromo-7-methoxy-benzofuran-2-substituted benzofuran derivatives. The present work involves the synthesis of key intermediate 5-Bromo-7-methoxy-benzofuran-2-carboxylicacid hydrazide (substituted benzylidine) hydrazides (1a-f) by treating 5-Bromo-7-methoxy-benzofuran-2-carboxylic acid hydrazide with various aromatic aldehydes. Compounds 1a-f were converted into 3-(substituted-benzyl)-5-(5-bromo-7-methoxy-benzofuran-2-yl)-3H-[1, 3, 4]oxadiazole-2-thiones(2a-f) by the reaction with carbon disulfide Compounds 1a-f were further converted into 1-[2-(aryl)-5-bromo-(7-methoxy-benzofuran-2-yl)-[1, 3, 4] oxidiazol-3-yl]-ethanoxy3(a-f), 5-Bromo-7-methoxy-benzofuran-2-carboxylic acid [2-(aryl-4-oxo-thiazolidin-3-yl)]-amides(4a-f) and 5-Bromo-7-methoxy-benzofuran-2-carbaxylic acid [2-(aryl)-4-oxo-3-phenyl-azetidin-1-yl-amide(5a-f) by treating with acetic anhydride, thioglycolic acid and phenyl-acetic acid-thionyl chloride respectively. Synthesised compounds were characterised by IR, H^1NMR and Mass spectroscopy, and were screened for Antibacterial and anti fungal activity with various organism and which are compared with standard drugs.

Keywords: *Benzofuran, substituted benzylidine, anti-bacterial activity, antifungal activity.*

Introduction

Recent studies indicated that, modern medicine has taken commendable strides due to advance Technology, also synthesis of fused heterocyclic compounds and their pharmacological activities gave progressive and effective results in the last few decades [01]. Many of β-azetidionone derivatives from chalcones of 4-hydroxycoumarin were (reported) exhibited by Pawar et al [02]. The newly Synthesised compounds were screened in vitro for their antimicrobial activity against a variety of bacterial strains. [,3] A series of 3-chloro-4-(3-methoxy-4-acetyloxyphenyl)-1-[3-oxo-3-(phenylamino) propanamido] azetidin-2-ones were developed by Halve et.al. [04 - 10]

The benzo[b]thiophene nucleus in the various 2-azetidinone exhibits significant antitubercular agent and also the compound with 3, 4-dimethoxyphenyl substitution showed excellent activity. [11] The chymase inhibitor activity of the series of 3-benzylazetidine- 2-one derivatives was predominant against human chymase which was designed by Aoyama et al. [12] The compound (2S,3R)-1-(4-(tert-butylcarbamoyl) piperazine-1-carbonyl)-3-(3-guanidinopropyl)-4-oxoazetidine-2-carboxylic acid, which comes under the series of N1-activated C4-carboxy azetidinones was synthesised and have tested as inhibitors of human tryptase [13].

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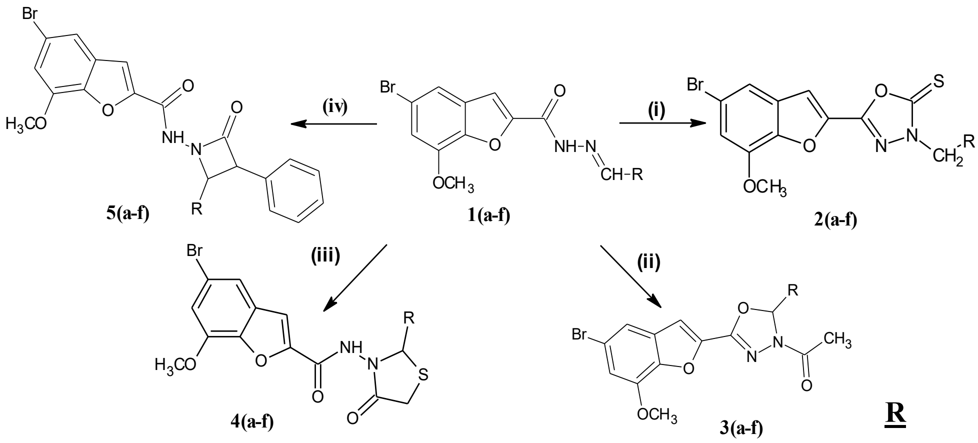
For the discovery and development of a highly diastereoselective demethoxycarbonylation of diester, Qian et al. have produced effective stereoselective synthesis of (2S,3R)-1-(4-(tert-butylcarbamoyl) piperazine-1-carbonyl)-3-(3-guanidinopropyl)-4-oxoazetidine-2-carboxylic acid. [14-16]
A number of efficient azetidinone tryptase inhibitors was synthesised by Bisacchi et al. The guanidine moiety which is present at C-3 position of the ring was replaced with primary or secondary amine or aminopyridine [17].

The effective and highly stable inhibitors of HLE (human leukocyte elastase) were prepared by the mechanism of inhibition of HLE by a monocyclic β-lactam and by the mechanism of β-lactam hydrolysis. This is because of the methyl or methoxy group in the para position of the benzene ring. [18,19] Human leukocyte elastase (HLE) inhibitor activity of azetidinones derivatives was evaluated by Cvetovich et al. [20] Monocyclic β-lactams identified as potent and unique inhibitors of the human cytomegalo virus protease (HCMV) with an IC_{50} of 0.07 mM [21-22]. Manjunatha Harihara Mathada et al have designed the copmound 5-bromo-7-methoxy-2-carbohydrazide, the synthesised compounds have shown excellent Anti bacterial and antifungal activity against various organisms [23].

Material and Methods

SCHEME



R

a=C_6H_5
b= $C_6H_5NO_2$ (p)
c= C_6H_5Cl (O)
d= C_6H_5Cl (m)
e= C_6H_5OH (O)

Conditions

(i) CS_2, KOH,C_2H_5OH
(ii) $(CH_3CO)_2O$
(iii) HS-CH_2-COOH, Anhydrous $ZnCl_2$, DMF
(iv) Phenyl acetic acid, thionyl chloride, dry benzene

Experimental Procedure

3-(substituted-benzyl)-5-(5-bromo-7-methoxy-benzofuran-2-yl)-3H-[1, 3, 4] oxadiazole-2-thiones 2 (a-f): 5-Bromo-7-methoxy-benzofuran-2-carboxylic acid hydrazide (substituted benzylidine) hydrazides 1 (a-f) (0.01mol) were taken in ethanol (20ml). To this solution potassium hydroxide (0.05g, 0.008mol) and carbon disulphide (1ml, 0.013mol) were added. The reaction mixture was refluxed on a steam bath for 10hr. the solution was allowed to cool overnight and then dissolved in 150ml ice cold water. The resulting solution acidified with dil. HCl and allowed to stand for 12h. The solid thus obtained was filtered, air-dried and recrystallized from the suitable solvent. The IR data of the compounds **2(a-f)** are given in the **Table No. 01.** The ^1H NMR spectrum in $CDCl_3$ was exhibited three singlets at 3.84, and 5.8 ppm due to two OCH_3 and N-CH_2 protons respectively. The multiplet in the range of 6.38-7.14 ppm were due to the aromatic protons. The molecular ion peak was observed at m/z 416 and 418 **(Mol.weight: 416)** confirmed the formation of **2a.**

Table No.01. IR data of compound 2(a-f)

Compounds	Substituents 'R'	IR data (cm^{-1})		
		C-N	C=S	C=N
2a	C_6H_5	1300	1055	1580
2b	$C_6H_5NO_2$(p)	1305	1064	1586
2c	C_6H_5Cl (O)	1306	1071	1579
2d	C_6H_5Cl (m)	1298	1066	1588
2e	C_6H_5OH (O)	1312	1068	1587
2f	C_6H_5OH (P)	1311	1058	1590

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1-[2-(aryl)-5-(7-methoxy-benzofuran-2-yl)-[1, 3, 4] oxidiazol-3-yl]-ethanoxy3(a-f) : A mixture of 5-Bromo-7-methoxy-benzofuran-2-carboxylic acid hydrazide (substituted benzylidine) hydrazide 1(a-f) (0.01mol) and acetic anhydride (5ml) was refluxed for 3h on a water bath. It was cooled to room temperature, poured into ice cold water and the solid separated was recrystallized from the suitable solvent. The IR data of the compounds **3(a-f)** are presented in **Table No. 02.** To provide the additional evidences for the proposed structures, the ^{1}H NMR and mass spectrum of **3e** were recorded. The ^{1}H NMR spectrum in $CDCl_3$ was exhibited two singlets at 2.25 and 3.84 ppm due to CH_3 and OCH_3 protons respectively. The remaining protons were resonated as multiplet in the range of 6.35-7.46 ppm. The molecular ion peak was observed at m/z 432 **(Mol.weight: 430)** confirmed the formation of 3e.

Table No.02. IR data of compound 3(a-f)

Compounds	Substituents 'R'	IR data (cm^{-1})	
		C=O	C=N
3a	C_6H_5	1655	1578
3b	$C_6H_5NO_2$(p)	1635	1575
3c	C_6H_5Cl (O)	1626	1586
3d	C_6H_5Cl (m)	1630	1590
3e	C_6H_5OH (O)	1637	1580
3f	C_6H_5OH (P)	1636	1573

5-Bromo-7-methoxy-benzofuran-2-carboxylic acid [2-(aryl-4-oxo-thiazolidin-3-yl)]-amides 4(a-f) : A mixture of 5-Bromo-7-methoxy-benzofuran-2-carboxylic acid hydrazide (substituted benzylidine) hydrazide 1(a-f) (0.10mol) in DMF (10ml), thioglycolic acid (0.1) and anhydrous zinc chloride (0.01mol) was added and the contents were refluxed for 5h. The reaction mixture was poured into cold water. The resulting solid was washed with water, dried and recrystallized from the suitable solvent. The IR data of **4(a-f)** were given in **Table No.03.** To provide the additional evidences for the proposed structures, the ^{1}H NMR and mass spectrum of **4e** were recorded. The ^{1}H NMR spectrum in $CDCl_3$ was exhibited singlets at 5.92, 4.01 and 3.84 ppm due to S-CH-Ar, S-CH_2 and OCH_3 protons respectively. The aromatic protons were resonated in the range 6.91-7.56 ppm. A singlet was observed at 8.52 ppm due to NH proton. The molecular ion peak was observed at m/z 464 **(Mol.weight: 462)** is in confirmation with the assigned structure for **4e.**

Table No.03. IR data of compound 4(a-f)

Compounds	Substituents 'R'	IR data (cm^{-1})	
		C=O	-CH_2
4a	C_6H_5	1635	2925
4b	$C_6H_5NO_2$(p)	1638	2987
4c	C_6H_5Cl (O)	1632	2984
4d	C_6H_5Cl (m)	1655	2932
4e	C_6H_5OH (O)	1630	2933
4f	C_6H_5OH (P)	1643	2940

5-Bromo-7-methoxy-benzofuran-2-carbaxylic acid [2-(aryl)-4-oxo-3-phenyl-azetidin-1-yl-amide 5(a-f) : A mixture of 5-Bromo-7-methoxy-benzofuran-2-carboxylic acid hydrazide (substituted benzylidine) hydrazide 1(a-f) (0.01mol) and phenylacetic acid (0.01mol) was dissolved in dry benzene (20ml) with constant stirring and thionyl chloride (10ml) was added to it 0oC. After the complete addition, a solid mass was separated out which was filtered off, dried and recrystallized from the suitable solvent. The IR data of the remaining compounds **5(a-f)** are given in the **Table No.04.**

Table No.04. IR data of compound 5(a-f)

mpounds	Substituents 'R'	IR data (cm^{-1})		
		NH	C=O azetidinone	C=O carbohyhrazide
5a	C_6H_5	3423	1665	1583
5b	$C_6H_5NO_2$(p)	3420	1663	1588
5c	C_6H_5Cl (O)	3424	1664	1594
5d	C_6H_5Cl (m)	3455	1660	1587
5e	C_6H_5OH (O)	3465	1658	1590
5f	C_6H_5OH (P)	3470	1663	1591

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Results and Discussion

Antibacterial activity

The antimicrobial activities of different extracts and fractions were compared with standard antibacterial agent Azithromycin. The zone of inhibition was calculated by measuring the minimum dimensions of the zone of no bacteria.

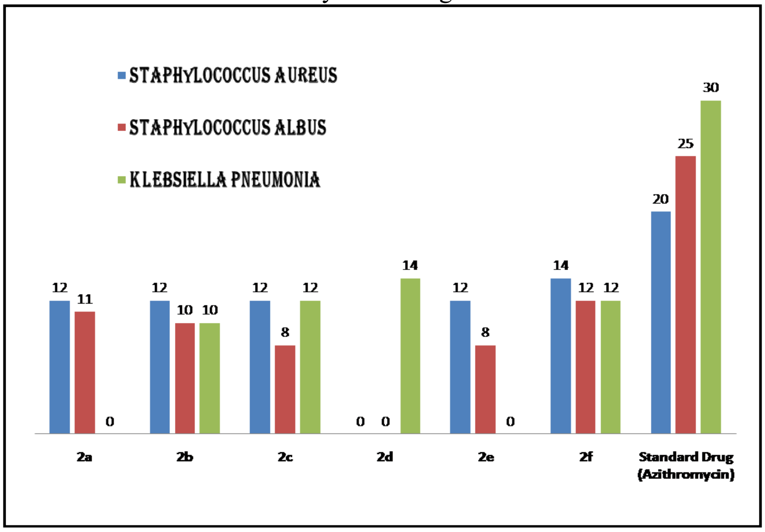

Figure 01: Antibacterial activity of the Compounds **2(a-f)** using a gram- positive and gram-negative organisms *Staphylococcus aureus, Staphylococcus albus,* and *Klebsiella pneumonia,* Comparision with the Standard Drug (Azithromycin)

Result revealed that the compound **2a** shows significant activity against Staphylococcus aureus, Staphylococcus albus,. Meanwhile compounds **2b, 2c,** exhibited good antibacterial activity and the compound **2d** does not show antibacterial activity against two organisms, it has shown promising activity against the organism Klebsiella pneumonia. The compound **2e** shows considerable results against two organisms. The compound **2f** which contains -OH group at the para position has shown excellent activity against all the three organisms.

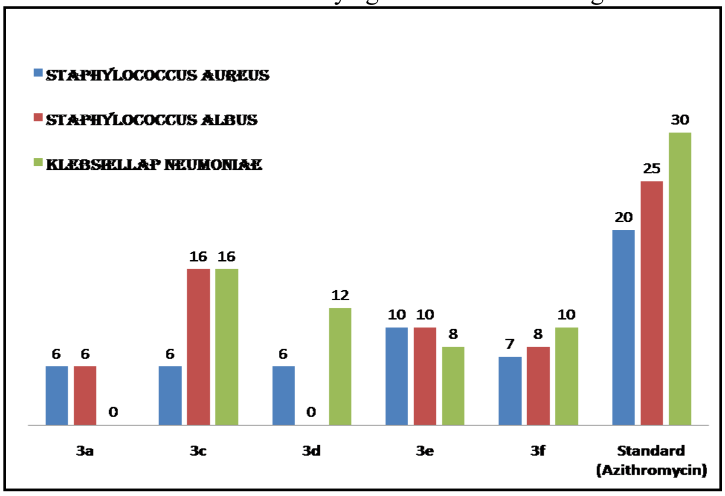

Figure 02: Antibacterial activity of the Compounds **3(a-f)** using a gram- positive and gram-negative organisms *Staphylococcus aureus, Staphylococcus albus,* and *Klebsiella pneumonia,* Comparision With the Standard Drug (Azithromycin)

Antibacterial activity of the compound **3a** was good for the organisms Staphylococcus aureus, Staphylococcus albus. The compound **3b** exhibits promising activity for all the three organisms. Ortho position of –Cl of the compound **3c** gave excellent activity compared to all the compounds, but the compound **3d** which contains –Cl group at the para position shown favorable activity with two organisms, but with the organism Staphylococcus albus it has not shown any activity. The compound **3e** which contains –OH group at ortho and the compound **3f** which contains –OH group at the para position has shown enormous antibacterial activity.

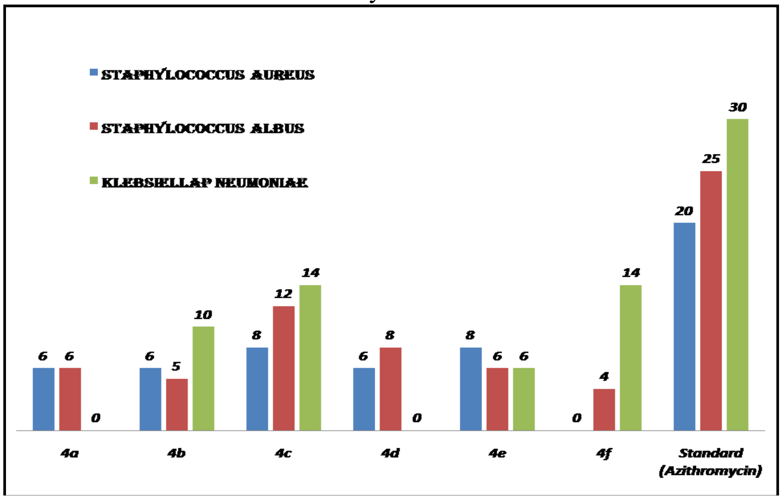

Figure 03: Antibacterial activity of the Compounds 4(a-f) using a gram- positive and gram-negative organisms *Staphylococcus aureus, Staphylococcus albus,* and *Klebsiella pneumonia,* Comparision with the Standard Drug (Azithromycin)

The comparative antibacterial activity of synthesized compounds has shown different results which is shown in **Figure 04**. Among the compounds, **4(a-e)** compound **6c** shown challenging activity against all the three organisms. The compound **4a** exhibits moderately active against Staphylococcus aureus, Staphylococcus albus and which shown poor activity against the bacteria Klebsiella pneumonia. Also –NO_2 group at para position in the compound **4b** has shown promising activity against the bacteria Klebsiella pneumonia, but it has shown favorable activity against the remaining two organisms. The compound **4d** which contains –Cl group at Meta position has shown potent activity against the two organisms Staphylococcus aureus, Staphylococcus albus and it showed poor activity against the organism Klebsiella pneumonia. The compound **4e** and **4f** which contain –OH group at ortho and para position respectively have shown significant activity for the organisms Staphylococcus aureus, Staphylococcus albus. But the compound **4f** does not any activity against the organism Klebsiella pneumonia.

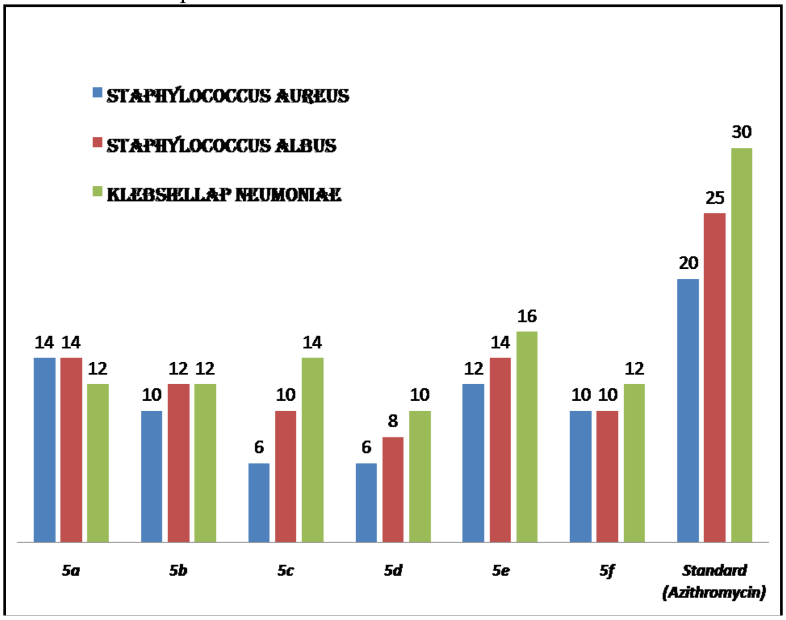

Figure 04: Antibacterial activity of the Compounds 5(a-f) using a gram- Positive and gram-negative organisms *Staphylococcus aureus, Staphylococcus albus,* and *Klebsiella pneumonia,* Comparision With the Standard Drug (Azithromycin)

The compound **5a** and **5e** have shown excellent activity against all the three organisms, also the compound **5b** and **5f** gave stabilizing activity compared to a standard drug which contains $–NO_2$, -OH group respectively. The compound **5d** which contains –Cl at meta position of the ring exhibits remarkable activity against the three organisms Staphylococcus aureus, Staphylococcus albus, and Klebsiella pneumonia, Comparision With the Standard Drug (Azithromycin).

Antifungal activity

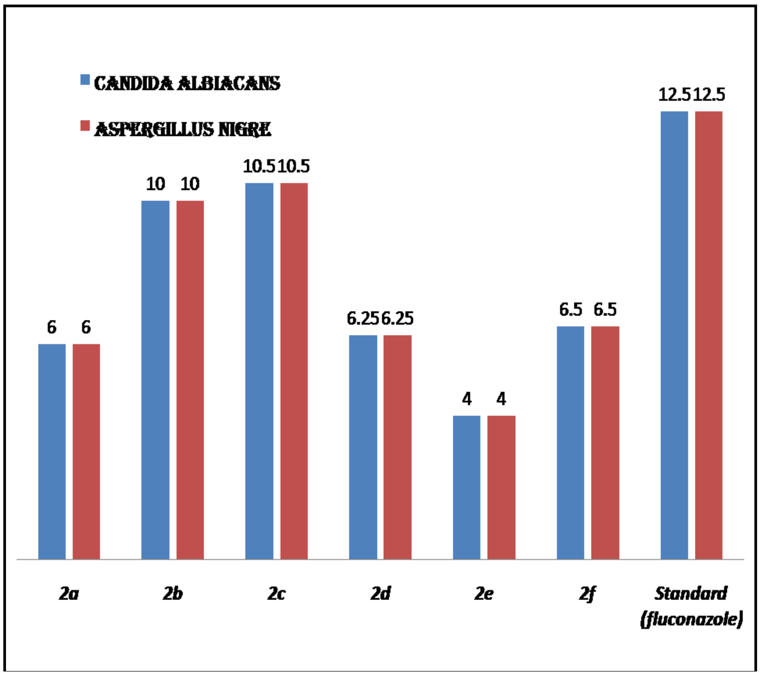

Figure 05: Antifungal activity of the Compounds **2(a-f)** using the organisms *Candida albiacans, Aspergillus nigre* With the Standard Drug (fluconazole)

Among the compounds **2(a-f)**, **2b** and **2c** have shown excellent activity against both the two organisms Candida albiacans, Aspergillus nigre and also this compound contains $–NO_2$ -Cl groups at para and ortho position respectively. The compounds **2a** and **2d** exhibit significant activity, in which **2d** contains –Cl group at meta position. The –OH group of the compound **2e** and **2f have** shown favourable activity against the two fungi compared with the standard drug.

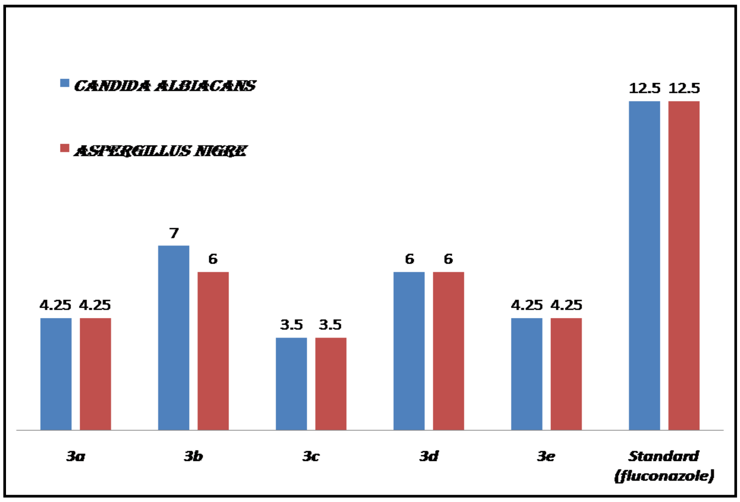

Figure 06: Antifungal activity of the Compounds **3(a-f)** using the organisms *Candida albiacans, Aspergillus nigre* With the Standard Drug (fluconazole)

Antifungal activity of the **3b** has shown potent activity against the two organisms Candida albiacans, Aspergillus nigre. The compound **3a** and **3e** exhibits remarkable activity against the two organisms which are compared with the standard

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drug fluconazole. Also, the compound **3c** has shown significant activity against the two organisms. And the compound **3f** which contains –OH group at the para position has shown promising activity against two fungi Candida albiacans, Aspergillus nigre.

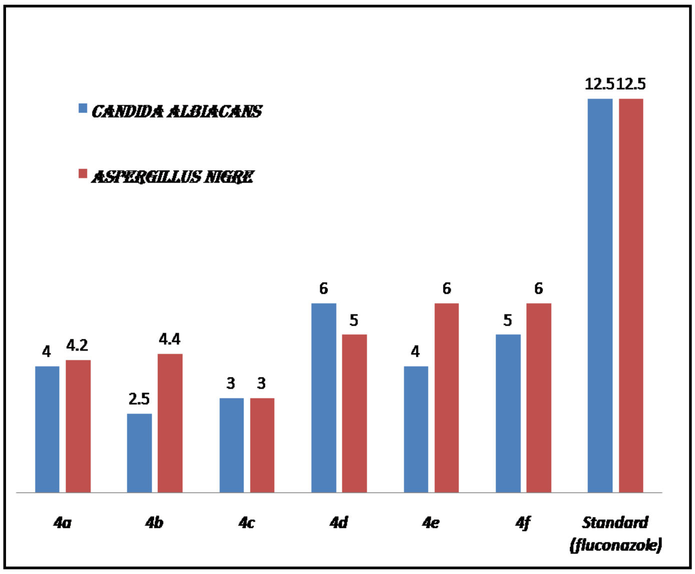

Figure 07: Antifungal activity of the Compounds **4(a-f)** using the organisms *Candida albiacans, Aspergillus nigre* With the Standard Drug (fluconazole)

The compound **4a** has shown predominant activity against the organism Aspergillus nigreThe compound **4b** exhibits good activity against the organism Aspergillus nigre, and with the organism Candida albiacans it has shown weak activity compare to the first fungi. Also the compound **4c** exhibits weak activity against both the fungi. Among the compounds **4(a-f), 4d, 4e, 4f** have given a significant activity the two fungi Candida albiacans, and Aspergillus nigre which are compared with the standard drug fluconazole which has shown in **Figure 07**.

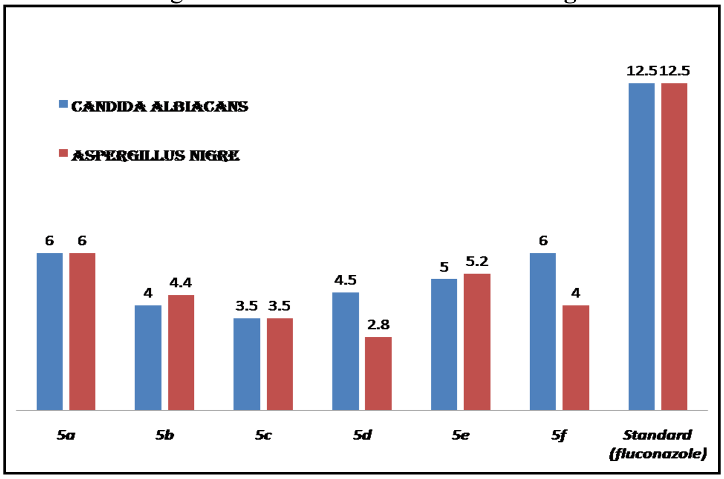

Figure 08: Antifungal activity of the Compounds **5(a-f)** using the organisms *Candida albiacans, Aspergillus nigre* With the Standard Drug (*fluconazole*)

Antifungal activity of **5(a-f)** have shown varied results, among have shown these compounds **5a** and **5f** have shown significant activity against two fungi Candida albiacans, Aspergillus nigre, but the remaining compounds **5b, 5c, 5e** and **5d** exhibits poor activity against two fungi Candida albiacans, Aspergillus nigre which are compared standard drug fluconazole which is tabulated in **Figure 08**.

Conclusion

All the compounds have exhibits prominent activity against the all organisms and which are compared with the standard drugs. Some of these compounds were shown weak activity at the zone of inhibition and some of shown excellent at the various zone of inhibition of the organisms,

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Original Article

Green synthesized Silver and Zinc oxide nanoparticles in bio-polymeric films for food preservation: A review

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Abstract

The increasing environmental concerns associated with synthetic plastic packaging have intensified research into biodegradable and compostable alternatives based on bio-derived polymers such as cellulose, chitosan, starch, carrageenan, and alginate. Although these biopolymers are non-toxic, biocompatible, and widely available, their standalone application in food packaging is often limited by inadequate mechanical strength and lack of bioactivity. To overcome these limitations, green synthesized metal nanoparticles, particularly silver (AgNPs) and zinc oxide nanoparticles (ZnO NPs), have emerged as promising functional additives due to their strong antimicrobial, antioxidant, UV-blocking, and barrier-enhancing properties. Green synthesis methods utilizing agro-waste materials rich in phytochemicals provide an eco-friendly, cost-effective, and non-toxic alternative to chemical approaches. Incorporation of these nanoparticles into biopolymeric matrices significantly improves physicochemical, mechanical, and biological performance, leading to enhanced food preservation and extended shelf life. This review highlights recent progress in the green synthesis of silver and zinc oxide nanoparticles and their application in biodegradable polymeric films for sustainable food packaging.

Introduction

Nowadays, focus on the development of bio-degradable and bio-compostable food packaging material is received top priority to cut down or minimize the usage of conventional plastic. Hence, most of the researchers are focusing on the usage of bio-derived polymers for the development of green and sustainable materials. The biopolymers like cellulose, chitosan, starch, carrageenan and alginate are more frequently used for the development of food packaging films due to their non-toxicity, biocompatibility, degradability and large availability. However, the development of bio-polymeric films alone is not sufficient to safeguard the packed food products. Hence, it is necessary for the packaging films to have bio-active property. In this regard, development of bio-active films using different additives such as natural extracts, metal nanoparticles, and other fillers attracts much more. Among the several additives, metal nanoparticles are considered to be most promising material due to their wide range of beneficial property such as antimicrobial, antioxidant, anti-UV and strong barrier towards water vapor and oxygen.

Utilizing nanomaterials is appealing because of their special qualities, which are only possible at the nanoscale. When compared to their micro- and macroscopic counterparts, materials at the nanoscale exhibit physical and chemical characteristics that are significantly different, which can have significant benefits for packaging materials [1]. Currently there are several approaches are adopted for the synthesis of the metal nanoparticles such as green and chemical methods. In the case of chemical approach, the chemical reagents are used as the reducing or precipitating agents for metal precursors those include sodium borohydrate, hydrazine hydrate, and formaldehyde. However, these chemicals cause toxicity over the nanoparticles [2]. To overcome this, green pigments and natural extracts are used as reducing agent in the case of green approach.

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Green approach is the simple, cost effective and most convenient method used for the synthesis of metal nanoparticles. The use of agro-waste material such as plant roots, leaves, fruit pulp and skin, and flower are more often used as reducing agent [3–6] due to their non-toxic behavior over the different concentration, availability, ease of handling, and comparatively low cost. Further, the agro-waste material such as garden leaves and fruit skin are being discarded as waste products but most of the fruit skin and leaves are rich in plant pigments such as polyphenols and flavonoids. For instance, every year around 110–120 million tons of citrus waste discarded worldwide [7] and that waste is rich in ascorbic acid which is a great source of ascorbic acid used for the synthesis of silver, copper and iron nanoparticles [8–10]. These natural plant phytochemicals mainly consist of several active pigments such as gallic acid, rutin, quercetin, and ascorbic acid. These pigments are considered as strong reducing in the synthesis of nanoparticles. The use of these green synthesized nanoparticles as the nanofillers or additives or cross-linkers in the bio-polymeric film matrices has significantly improved the physico-chemical and biological performance (Fig. 1). In this connection, most of the researches are trying to utilize the agro-waste products for the synthesis of nanoparticles and used them as additives in the polymeric films. Addition of these agro-waste derived nanoparticles not only enhance the physico-mechanical properties of the films, also act as food preservative due to the combined effect of metal nanoparticles and availability of plant pigment on the surface of the nanoparticles.

In this review article, we mainly focus on the use of different agro-waste products for the synthesis of nanoparticle and their potential use in degradable polymeric films for food packaging purpose have been summarized.

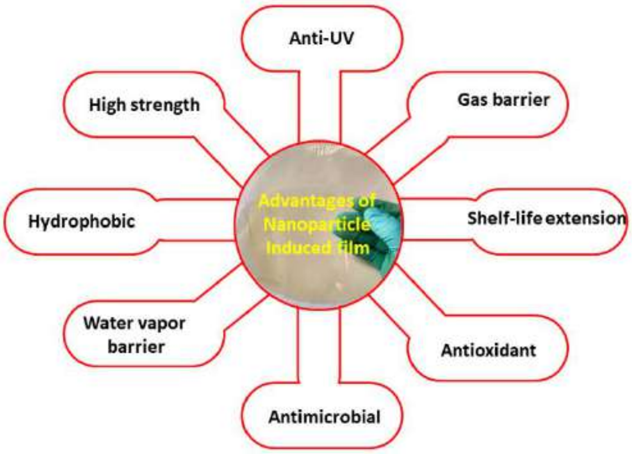

Fig. 1 Advantages of nanoparticle induced biopolymeric films

Green synthesis of nanoparticles

The green synthesis methods of nanoparticles involve processes that are environmentally friendly and non-toxic, frequently using natural sources or benign chemicals. There are several green synthesis methods currently being that used including plant extract, microorganisms, bio-waste, green solvents, solar irradiation, and microwave-assisted synthesis. These methods are considered to be more convenient, cost-effective and less hazardous. The mechanism involved in these methods is quite similar. Briefly, metal precursors were solubilized in aqueous solvent, then the green reduction of metal ion (M^+) takes place by the action of reducing agent (extracts, organisms, radiations, etc.). Then the reduced M^+ ions further undergo particle growth followed by the stabilization to form nanoparticles (Fig. 2)[11].

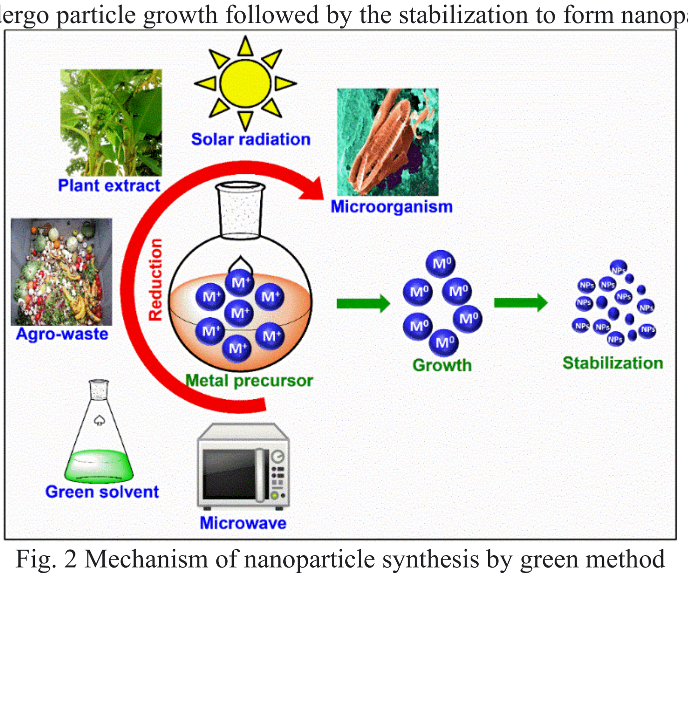

Fig. 2 Mechanism of nanoparticle synthesis by green method

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Green synthesized nanoparticles and their potential use in food packaging films

Silver nanoparticles

The utilization of silver nanoparticles (AgNPs) in food packaging systems has received much interest due to their wide range of applications. AgNPs can readily be synthesized using green reducing agents such as plant extracts and agro-waste products. Silver nanoparticles (AgNPs) have many beneficial properties, like high antioxidant and antimicrobial efficiency against most common foodborne pathogens, including*Staphylococcus aureus, Escherichia coli, Candida albicans, Aspergillus niger,* and *Pseudomonas aeruginosa.* Most of the studies have shown the utilization of AgNPs in the polymer matrices significantly enhanced the functional properties. For instance, Zhang & Jiang (2020) synthesized tea polyphenol-mediated AgNPs and incorporated them into the chitosan film matrix; they observed that the color of the chitosan film gradually turned brown. Further, the tensile properties of films remarkably improved due to the dense polymeric network caused by the AgNPs and the cross-linking ability of tea polyphenols [12]. Many of the researchers have used green extracts to synthesize AgNPs and found that the use of green synthesized AgNPs can significantly affect the functional properties of the film matrices [13–15]. More precisely, authors have claimed that AgNPs in the polymer blend films can enhance oxygen, moisture, and UV ray barrier properties[16]. Further, the bioactive capacities such as antibacterial, antifungal, and antioxidant properties of the films were enhanced significantly [17–19]. The improvement in the barrier and bioactive properties is mainly due to the excellent UV absorption and strong pathogen inhibition capacity of the AgNPs. The polymeric blend and composite film with green-extracted AgNPs have also shown practical potential to preserve the food products. *Ficus carica* mediated AgNPs embedded in chitosan film with natural kaolin clay interestingly displayed promising performance, including reduced moisture loss, a low browning index, a high overall phenolic content, and antioxidant activity of the apple slice when wrapped with the developed nanocomposite film. In addition, the carrot packed with AgNPs-integrated chitosan/gelatin composite film for ten days seemed fresh, with no signs of foulness or mildew, and showed a lower colony count than polyethylene. This increase in the functional property was mainly due to the microbial resistance capacity of the AgNPs and chitosan present in the film matrix [18]. Furthermore, Basumatary et al. used a medicinally valued *Lagerstroemia speciosa* fruit extract for the biosynthesis of AgNPs. These AgNPs were induced into an agar matrix to produce nanocomposite films. The results showed that the appearance, thermal stability, elongation at break, and antibacterial properties of the composite films were all enhanced by the addition of AgNPs[20]. The remarkable antibacterial efficiency of the nanocomposite film was strongly associated with the presence of medicinally active phytochemicals coated on the AgNPs surface; these tend to rupture the microbial cell wall membrane along with the AgNPs. It is observed that the dispersion of AgNPs and achieving homogeneity were quite challenging. There are various physical and chemical approaches beingemployed to overcome this problem. In the physical process, continuous stirring and ultrasonication were generally employed, while cross-linkingagents, surface modification, and copolymerization were used in the chemical approach. In contrast, the in-situ method of AgNPs generation within the polymer matrix enables high miscibility and homogeneity in the packaging films[21]. In a recent study, Gasti and co-workers synthesized AgNPs by an in-situ mechanism within the polymer matrix using guar gum as a reducing agent and PVA as a stabilizing agent[22]. It is noticed that the developed nanocomposite films had a smooth and glassy appearance with uniform dispersion of AgNPs. This method has not only improved the homogeneity but also increased the stretching efficiency due to the lack of solid dispersed AgNPs. As a result, this method of AgNPs synthesis was found to be more suitable for food packaging applications.

Nanoparticle	Salt precursor	Green reducing agent	Polymer matrix	Packed food product	Shelf-life extension (Days)	Reference
Ag	$AgNO_3$	*Eucalyptus camaldulensis* leaves	PVA/CS	Chicken sausage	15	Ref [23]
	$AgNO_3$	*Mentha* leaves	CMC/Guar gum	Strawberry	6	Ref [24]
	$AgNO_3$	Basil leaves	SA/Gum acacia	Black grapes	18	Ref [25]
	$AgNO_3$	*Mimusopselengi*fruit	CS/Gel	Black grapes	14	Ref [26]
	$AgNO_3$	Pomegranate peel	Cellulose	Bread	7	Ref [27]
	$AgNO_3$	Kinnow fruit peel	Cellulose	Bread	7	Ref [27]
	$AgNO_3$	Guar gum	PVA	-	-	Ref [22]
ZnO	$Zn(NO_3)_2\ 6H_2O$	*Mimusopselengi*fruit	Agar	Grapes	21	Ref [28]

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	(Zn $(CH_3COO)_2.2H_2O$)	Hydrothermal	Starch	Strawberry	10	Ref [29]
	Zn $(NO_3)_2$ $6H_2O$	*Citrus sinensis waste*	PVA/CS	-	-	Ref [30]
	Zn $(NO_3)_2$ $6H_2O$	*Musa acuminata leaf*	CS	Poultry meat	7	Ref [31]

CS – chitosan, PVA – polyvinyl alcohol, CMC – carboxymethyl cellulose, SA – sodium alginate,

Zinc nanoparticles (ZnO NPs)

Zinc oxide nanoparticles are another class of simple nanoparticles largely utilized in wide range of applications due to their low toxicity and wide range of bio-medical applications. Now a day, ZnO is more being used in numerous aspects of everyday life, such as drug delivery, beauty products, healthcare implants, dental work, and orthopedics. The US Food and Drug Administration (FDA) considered ZnO as the safe ingredient in the food systems. As a result, most of the food industries are using ZnO NPs as the nutrient in food supplements. ZnO NPs are well known for their high antioxidant and excellent antimicrobial properties. Therefore, insertion of ZnO NPs into the polymer matrices for food packaging application is received much interest. It is evidenced from the ongoing research that ZnO NPs were enormously incorporate into different form of food packaging systems to achieve improved functional properties[32]. Recently, mango peel ash used as green reducing agent for the synthesis of ZnO NPs and were incorporated in poly (vinyl alcohol)/chitosan film matrix to enhance physico-mechanical properties [33]. Dulta et al. used *Carica papaya* leaf extract for the synthesis of ZnO NPs and were induced into chitosan and alginate matrix. These developed formulations were practically exposed to the preservation of oranges. The chitosan coating containing 0.5 gL^{-1} ZnO NPs had shown not only reduced the proportion of decaying fruit and caused weight loss, but also preserved the quality of the orange fruit by reducing respiration, as a result increased shelf-life of 20 days[34]. The presence of polyphenol oxidase in the *Carica papaya* leaf extract triggers the enhanced activity of ZnO NPs induced chitosan coating. In a recent study, Alamdari et al. developed chitosan-based hybrid film containing ZnO NPs synthesized using aqueous extract of *wild Mentha pulegium*leaves. The fabricated chitosan/ZnO NPs (5wt%) was practically tested for the preservation of strawberry and red plum at room temperature[35]. It was observed that, the fruits covered with chitosan/ZnO NPs nanocomposite film was remain fresh and retained glassy texture. The high antioxidant and antimicrobial of the film delayed the oxidation and microbial growth on the fruit surface, hence extended shelf-life.

Conclusion

Green synthesized silver and zinc oxide nanoparticles play a pivotal role in advancing sustainable food packaging technologies by enhancing the functional performance of biodegradable polymer films. The use of agro-waste–derived phytochemicals for nanoparticle synthesis not only reduces environmental impact but also improves nanoparticle stability and bioactivity. When incorporated into bio-polymeric matrices, these nanoparticles enhance mechanical strength, thermal stability, barrier properties, and antimicrobial efficiency, thereby effectively extending the shelf life of various food products. Silver nanoparticles demonstrate broad-spectrum antimicrobial activity, while zinc oxide nanoparticles offer excellent antioxidant properties and regulatory acceptance for food applications. Despite promising laboratory-scale results, challenges such as nanoparticle dispersion, large-scale production, safety evaluation, and regulatory compliance remain to be addressed. Future research should focus on optimizing synthesis methods, ensuring consumer safety, and developing scalable production strategies to fully realize the commercial potential of green nanoparticle-incorporated biodegradable packaging materials.

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Original Article

The Role of Mathematics in Artificial Intelligence and Machine Learning

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Abstract

Artificial Intelligence (AI) and Machine Learning (ML) have rapidly transformed various sectors including healthcare, banking, transportation, education, and governance. AI refers to the ability of machines to simulate human cognitive functions such as learning, reasoning, and decision-making, while ML enables systems to learn from data and improve over time without explicit programming. Despite their technological appearance, these systems are fundamentally built upon mathematical principles. Mathematics provides the theoretical foundation and computational tools necessary for constructing intelligent algorithms and predictive models.

This paper highlights the essential role of mathematics in AI and ML, focusing on key domains such as linear algebra, calculus, probability theory, and optimization. Linear algebra enables efficient data representation through vectors and matrices, while calculus supports learning processes through gradient-based optimization and back propagation. Probability theory addresses uncertainty and supports predictive modeling, and optimization techniques help determine optimal model parameters. The paper emphasizes that a strong mathematical foundation is necessary to develop reliable, efficient, and transparent AI systems. As AI continues to expand across society, collaborative efforts are required to ensure accountability, fairness, and ethical deployment.

Introduction

Artificial Intelligence (AI) and Machine Learning (ML) are among the most transformative technological innovations of the modern era. AI systems are designed to perform tasks that traditionally require human intelligence, such as visual perception, speech recognition, decision-making, and problem-solving. ML, a subset of AI, allows machines to learn patterns from data and improve their performance through experience. These technologies are now integrated into numerous sectors including healthcare diagnostics, financial forecasting, autonomous vehicles, recommendation systems, and smart devices. However, behind these sophisticated applications lies a strong mathematical framework that enables machines to process data, learn patterns, and make predictions accurately.

To design effective AI and ML systems, it is essential to understand their mathematical foundations. Linear algebra supports high-dimensional data manipulation; calculus enables optimization of models; probability theory handles uncertainty; and optimization methods help identify the best parameters for predictive performance. This paper explores how these mathematical disciplines contribute to AI and ML development and demonstrates their importance in building intelligent systems.

Mathematics in Artificial Intelligence: An Overview

Mathematics serves as the backbone of AI systems. Without mathematical modeling, it would be impossible to design algorithms capable of learning from complex data. The major mathematical fields contributing to AI include:

- Linear Algebra
- Calculus

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- Probability Theory
- Optimization Techniques

Each of these areas plays a specific and interconnected role in AI development.

Linear Algebra in AI and Machine Learning

Linear algebra is fundamental to AI because most data used in ML models is represented in numerical form using vectors and matrices.

Data Representation: Vectors and Matrices

In AI:

- A **vector** represents a single data instance or feature set.
- A **matrix** represents a dataset where rows correspond to observations and columns correspond to features.

Matrix operations such as addition, multiplication, and inversion are central to machine learning algorithms. Neural networks rely heavily on matrix multiplication during forward propagation, where inputs are multiplied by weights to generate outputs.

Eigenvalues and Eigenvectors

Eigenvalues and eigenvectors are critical in understanding data transformations and dimensionality reduction. They help identify the most significant directions in high-dimensional data, improving computational efficiency and model performance.

Principal Component Analysis (PCA)

PCA reduces data dimensionality by computing eigenvectors and eigenvalues of a covariance matrix. This process:

- Reduces redundancy
- Lowers computational cost
- Preserves essential information

Dimensionality reduction enhances model efficiency without significant loss of accuracy.

Singular Value Decomposition (SVD)

SVD decomposes a matrix into three components (U, Σ, V^T). It is widely used in:

- Recommendation systems
- Collaborative filtering
- Data compression
- Latent semantic analysis

By uncovering hidden patterns in data, SVD improves predictive systems.

Matrix Decomposition Methods

LU and Cholesky decomposition are used in:

- Solving linear equations
- Optimizing regression models
- Improving computational efficiency

Linear algebra therefore provides the structural framework for AI models.

Calculus Applications in AI and ML

Calculus, particularly differential calculus, plays a crucial role in training machine learning models.

Differentiation and Gradient Computation

Differentiation is used to compute gradients, which indicate how model parameters should change to reduce errors. This is central to:

- Gradient Descent
- Backpropagation

Backpropagation applies the chain rule of calculus to calculate partial derivatives of the loss function with respect to each parameter in a neural network.

Optimization of Loss Functions

Loss functions measure prediction error. Calculus helps:

- Identify minimum points
- Adjust weights iteratively
- Improve model accuracy

Convex and Non-Convex Optimization

- Convex functions have a single global minimum, ensuring stable optimization.

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- Non-convex functions, common in deep learning, may contain multiple local minima.

Advanced techniques such as momentum and stochastic methods help navigate complex optimization landscapes.

Multivariate Calculus

Deep learning models involve numerous parameters. Multivariate calculus allows computation of partial derivatives for each parameter, ensuring effective learning across layers.

Second-Order Optimization

Methods such as Newton's method use second derivatives (Hessian matrices) to improve convergence speed. Though computationally expensive, they provide stability in optimization.

Integration and Regularization

Integration supports:

- Continuous activation function analysis
- L2 regularization
- Probability distribution modeling

Thus, calculus enables continuous improvement of AI models.

Probability Theory in AI and ML

AI systems operate under uncertainty. Probability theory provides a framework for managing randomness and incomplete information.

Probabilistic Modeling

Probability underlies:

- Bayesian networks
- Markov decision processes
- Probabilistic graphical models

These models allow AI systems to make predictions even with uncertain data.

Bayesian Inference

Bayesian methods update prior beliefs with observed data to calculate posterior probabilities, improving predictive reliability.

Statistical Foundations

Machine learning relies on probability distributions to:

- Estimate parameters
- Measure likelihood
- Assess risk

Probability ensures rational and evidence-based decision-making.

Optimization Techniques in Machine Learning

Optimization determines the best model parameters to minimize error.

Gradient Descent

Gradient descent iteratively updates parameters based on computed gradients. Variants such as Stochastic Gradient Descent (SGD) improve efficiency.

Convex Optimization

Convex optimization guarantees global solutions and is used in:

- Linear regression
- Logistic regression
- Support Vector Machines (SVMs)

Non-Convex Optimization

Deep neural networks often involve non-convex problems. Advanced optimization methods help escape local minima and achieve better performance.

Constrained Optimization

Lagrange multipliers help solve optimization problems with constraints, ensuring feasible solutions.

Optimization bridges mathematical theory and practical AI implementation.

Mathematics in Machine Learning

Machine learning depends heavily on mathematical modeling.

Supervised Learning
Supervised learning uses labeled data to train models.

(c) Classification
Classification predicts discrete labels (e.g., spam detection). Logistic regression uses the sigmoid function to estimate probabilities.

(b) Regression
Regression predicts continuous values (e.g., house prices). Linear regression models relationships using linear equations.

© Neural Networks
Artificial Neural Networks consist of layers of interconnected neurons. Training involves:

- Matrix operations
- Backpropagation
- Loss minimization

Mathematics ensures accurate generalization.

Unsupervised Learning
Unsupervised learning works with unlabeled data to discover hidden patterns.
Key techniques include:

- Clustering
- Dimensionality reduction
- Pattern detection

Linear algebra and probability enable grouping and structure discovery.

Intersection Between Mathematics and AI Applications
Mathematics is not only theoretical but also practical in AI systems.

Computer Vision
Linear algebra, calculus, and optimization are used for:

- Image classification
- Feature extraction
- Object recognition

Object Detection
Graph theory and probability help detect and track objects in images.

Recommendation Systems
Matrix factorization and SVD power recommendation engines used in streaming and e-commerce platforms.

Healthcare and Engineering
AI assists in:

- Medical diagnosis
- Energy optimization
- Reliability modeling

All these applications rely heavily on mathematical modeling.

Conclusion
Mathematics is the fundamental foundation of Artificial Intelligence and Machine Learning. Linear algebra enables data representation and transformation. Calculus supports learning through gradient-based optimization. Probability theory manages uncertainty and predictive reasoning. Optimization techniques ensure efficient parameter estimation and performance enhancement.

AI and mathematics are deeply interconnected; progress in one drives advancement in the other. As AI continues to expand into everyday life—autonomous vehicles, smart healthcare, intelligent assistants—strong mathematical understanding remains essential.

Future AI development depends on continued mathematical research and interdisciplinary collaboration. To ensure responsible deployment, stakeholders must prioritize transparency, fairness, privacy, and accountability. With a solid mathematical foundation and ethical oversight, AI can effectively address complex societal challenges and drive innovation responsibly.

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Original Article

Shortest Distance Analysis from Tumkur City Bus Stand to Mc Colony Using Graph Theory

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Abstract

Transportation networks play a crucial role in modern urban life by supporting activities such as commuting education commerce and healthcare. Efficient route planning is essential to minimize travel time fuel consumption and traffic congestion.

This study demonstrates the application of Graph Theory in determining the shortest travel distance between Tumkur City Bus Stand and MC Colony a prominent residential area in Tumakuru. Road intersections are modeled as vertices and connecting roads as weighted edges. Dijkstra's Algorithm is employed to compute the shortest path within the transportation network. The findings highlight the practical relevance of mathematical models in real world transportation planning and urban infrastructure optimization.

Keywords: *Graph Theory Shortest Path Dijkstra's Algorithm Transportation Network Urban Planning*

Introduction

Transportation infrastructure is a fundamental component of urban development. As cities expand road networks become increasingly complex making route optimization a challenging task. Identifying efficient routes is essential for reducing travel time fuel usage and environmental impact.

Tumkur City Bus Stand is one of the busiest transit hubs in the city while MC Colony serves as a major residential locality. A significant number of commuters travel between these two locations daily. This study applies Graph Theory to systematically analyze the shortest route between them.

Overview Of Graph Theory

Basic Terminology

- Vertex or Node represents a location such as a junction or bus stop
- Edge represents a road connecting two locations
- Weighted Graph is a graph in which edges have numerical values representing distance or cost
- Path is a sequence of connected edges
- Shortest Path is the path with the minimum total weight

Importance Of Graph Theory

Graph Theory has extensive applications in road networks railway systems airline routing computer networks and GPS navigation systems. It provides a strong mathematical framework for transportation analysis.

Transportation Network Modeling

An urban transportation network can be represented as a weighted graph by treating intersections and important locations as vertices representing roads as edges and assigning distances as weights.

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In this study the bus stand serves as the source vertex while MC Colony represents the destination vertex.

Advantages Of Graph Based Modeling

Graph based modeling enables efficient route identification reduction in fuel consumption improved traffic flow analysis and better urban infrastructure planning.

Shortest Path Problem

The shortest path problem involves determining the minimum distance route between two vertices in a weighted graph. Real world applications include navigation systems emergency vehicle routing logistics delivery services and public transportation scheduling.

Study Area Bus Stand to Mc Colony

The selected route is significant due to daily student and employee travel dependence on public and private transport and high traffic density. Major intermediate junctions considered include Town Hall Circle Ashoka Road Junction SIT Main Road and connecting roads to MC Colony. These junctions are modeled as vertices in the graph.

Methodology

- Identification of major road junctions
- Representation of each junction as a vertex
- Assignment of road distances as edge weights
- Application of Dijkstra's Algorithm
- Selection of the minimum distance path

Dijkstra's Algorithm

Dijkstra's Algorithm is a widely used method for solving shortest path problems in weighted graphs.
It operates on non negative edge weights determines shortest paths from a single source and is suitable for transportation networks.

Practical Distance Calculation

- Bus Stand to Town Hall 1.2 km
- Town Hall to Ashoka Road 1.0 km
- Ashoka Road to SIT Road 1.5 km
- SIT Road to MC Colony 1.3 km

The total distance is approximately 5.0 km and is identified as the shortest route.

Alternative Routes

Alternative routes include paths via Market Road and Ring Road. Graph Theory helps in comparing all possible routes to identify the optimal one.

Benefits Of Shortest Path Analysis

Shortest path analysis helps in saving travel time reducing fuel consumption minimizing traffic congestion and improving emergency response services.

Limitations

Shortest distance routes may be affected by traffic congestion road maintenance signal delays and weather conditions. Therefore, shortest distance does not always represent shortest travel time.

Conclusion

This study demonstrates the application of Graph Theory in urban transportation planning by identifying the shortest route between Tumkur City Bus Stand and MC Colony. The use of Dijkstra's Algorithm shows how mathematical methods can effectively solve real world problems in navigation traffic management and urban development.

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Original Article

Some results on value distribution for nth difference operator of meromorphic functions with relative (k; n) Valiron defect

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Abstract

Abstract. In this paper, we investigate and compare the value distribution of nth difference operator of meromorphic functions focusing on relation between relative (k; n) Valiron defect with the relative Nevanlinna defect for higher order exact dif- ference of f (z), where k and n are both non negative integers.

Keywords: *Nevanlinna theory, Meromorphic functions, Valiron defect and Nevan- linna defect.*
Subject Classification: 30D35

1 Introduction and results

Let $f(z)$ be a meromorphic function in the complex plane $\mathbb{C}$. We are using the notations of Nevanlinna theory of meromorphic functions (see[23]) such as,

$$T(r,f),\ m(r,f),\ N(r,f),\ m(r,a)=m\left(r,\frac{1}{f-a}\right),\ N(r,a)=N\left(r,\frac{1}{f-a}\right)$$

etc. A meromorphic function $a(z)$ is said to be a small function of f, if $T(r,a) = S(r,f)$, where $S(r,f)=o(T(r,f))$, as $r\to\infty$, without ristriction if $f(z)$ is of finite order and otherwise except possibly for a set of values of r of finite linear measure.

For a meromorphic function $f(z)$ and a nonzero constant c, $n\in\mathbb{N}$ we define its shipts by $f(z+c)$ and its difference operator by

$$\Delta_c f(z)=f(z+c)-f(z)$$

and

$$\Delta_c^n f(z)=\sum_{j=0}^{n}\binom{n}{j}(-1)^{n-j}f(z+jc),$$

where

$$\binom{n}{j}=\frac{n!}{j!(n-j)!}$$

If in the above inequality, equality holds, then we say that f has maximal deficiency sum.
The order ρ_f of a meromorphic function is defined as follows

$$\rho_f=\overline{\lim_{r\to\infty}}\frac{\log T(r,f)}{\log r}.$$

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If $\rho_f < \infty$, then f is of finite order.

The Nevanlinna defect $\delta(a, f)$ and Valiron defect $\Delta(a, f)$ of a for meromorphic function are respectively defined as follows

$$\delta(a, f) = \varliminf_{r\to+\infty} \frac{m(r, a, f)}{T(r, f)} = \varlimsup_{r\to+\infty} \frac{N(r, a, f)}{T(r, f)}$$

and

$$\Delta(a, f) = \varlimsup_{r\to+\infty} \frac{m(r, a, f)}{T(r, f)} = \varlimsup_{r\to+\infty} \frac{N(r, a, f)}{T(r, f)}.$$

The relative Nevanlinna defect of α for $\Delta_c f$ with respect to $f^{(k)}$ is defined as follows

$$\delta_R^{(k)}(a, \Delta_c^{(k)} f) = \varliminf_{r\to+\infty} \frac{m(r, \alpha, \Delta_c^{(k)} f)}{T(r, f)} = \varlimsup_{r\to+\infty} \frac{N(r, \alpha, \Delta_c^{(k)} f)}{T(r, f)},$$

for k=1,2,3,...

The relative (k, n) Nevanlinna defect of α for $\Delta_c f$ with respect to $f^{(k)}$ for $k = 1, 2, 3, ...$ and $n = 0, 1, 2, 3, ...$ is defined as follows

$$\delta_{R(n)}^{(k)}(\alpha, \Delta_c^{(k)} f) = \varliminf_{r\to+\infty} \frac{m(r, \alpha, \Delta_c^{(k)} f)}{T(r, \Delta_c^{(n)} f)} = \varlimsup_{r\to+\infty} \frac{N(r, \alpha, \Delta_c^{(k)} f)}{T(r, \Delta_c^{(n)} f)}$$

and the relative (k, n) Valiron defect of α for with respect to $f^{(k)}$ for $k = 1, 2, 3, ...$ and $n = 0, 1, 2, 3, ...$ is defined as follows

$$\Delta_{R(n)}^{(k)}(\alpha, \Delta_c^{(k)} f) = \varlimsup_{r\to+\infty} \frac{m(r, \alpha, \Delta_c^{(k)} f)}{T(r, \Delta_c^{(n)} f)} = \varliminf_{r\to+\infty} \frac{N(r, \alpha, \Delta_c^{(k)} f)}{T(r, \Delta_c^{(n)} f)}.$$

The **Valiron-Mo'honko identity** says that: If the function $R(z, f)$ is rational function in f and has co-efficients as small meromorphic functions, then

$$T(r, R(z, f)) = deg_f(R)T(r, f) + S(r, f). \tag{1.1}$$

2 Some Lemmas

We need the following Lemmas to prove our results.

Lemma 2.1. [13] *Let $f(z)$ be a transcendental meromorphic function of order $\sigma(< 1)$, and let c be a non-zero complex number. Then*

$$m\left(r, \frac{f(z+c)}{f(z)}\right) = o(T(r, f)) = S(r, f).$$

Lemma 2.2. [13] *Let $f(z)$ be a transcendental meromorphic function of order $\sigma(< 1)$, and let c be a non-zero complex number. Then*

$$m\left(r, \frac{\Delta_c^n f(z)}{f(z)}\right) = o(T(r, f)) = S(r, f).$$

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Lemma 2.3. [13] *Let $f(z)$ be a transcendental meromorphic function of order less than one and let c be a non-zero complex number. Then*

$$N(r, f(z+c)) = N(r, f) + S(r, f).$$

Lemma 2.4. [13] *Let $f(z)$ be a transcendental meromorphic function of order less than one and let c be a non-zero complex number. Then*

$$N(r, \Delta_c^n f(z)) \leq \sum_{j=0}^{n} \binom{n}{j} N(r, f) + S(r, f).$$

Lemma 2.5. [13] *Let $f(z)$ be a transcendental meromorphic function of order less than one and let c be a non-zero complex number and n be a non negative integer. Then*

$$N(r, f) \leq N(r, \Delta_c^n f(z)).$$

In 2019, Bhoosnurmath ([13])proved the following theorem

Theorem 2.1. *Suppose that $f(z)$ is a transcendental meromorphic function of order less than one. Then we have*

$$\sum_{a\in\mathbb{C}} \delta(a, f) \leq \varliminf_{r\to\infty} \frac{T(r, \Delta_c^n f)}{T(r, f)} \leq \varlimsup_{r\to\infty} \frac{T(r, \Delta_c^n f)}{T(r, f)} \leq (n+1) - n\delta(\infty, f). \quad (2.1)$$

(i) For $n = 1$ with maximal deficiency sum and $\sum_{a\in\mathbb{C}} \delta(a, f) = \alpha$, $(1 \leq \alpha \leq 2)$

$$T(r, \Delta_c f) \sim \alpha T(r, f), \quad as \quad r \to \infty.$$

(ii) For $n \geq 1$ with $\sum_{a\in\mathbb{C}} \delta(a, f) = 1$ and $\delta(\infty, f) = 1$,

$$\lim_{r\to\infty} \frac{T(r, \Delta_c^n f)}{T(r, f)} = 1.$$

Theorem 2.2. [22] *Let $f(z)$ is a transcendental meromorphic function of finite order less than one and $\delta(\infty, f) = 1$, then*

$$\sum_{a\in\mathbb{C}} \delta(a, f) \leq \delta(0, \Delta_c f).$$

Here we prove some lemmas which will be useful to prove our main results

Lemma 2.6. *Let $f(z)$ is a transcendental meromorphic function of finite order and $\sum_{a\in\mathbb{C}} \delta(a, f) = 1$ and $\delta(\infty, f) = 1$, then*

$$\lim_{r\to+\infty} \frac{T(r, \Delta_c f)}{T(r, f)} = 1.$$

Proof. We omit the proof of Lemma 2.1 because it can be carried out in the similar lines of Theorem 2.1.

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Lemma 2.7. *Let $f(z)$ is a transcendental meromorphic function of finite order and $\sum_{a\in\mathbb{C}}\delta(a,f)=1$ and $\delta(\infty,f)=1$, then for a non-negative integer k,*

$$\lim_{r\to+\infty}\frac{T(r,\Delta_c^{(k)}f)}{T(r,f)}=1.$$

Proof. We omit the proof of Lemma 2.2 because it can be carried out in the similar lines of Lemma 2.1.

Lemma 2.8. *Let $f(z)$ is a transcendental meromorphic function of finite order and $\sum_{a\in\mathbb{C}}\delta(a,f)=1$ and $\delta(\infty,f)=1$, then for a non-negative integer k,*

$$\lim_{r\to+\infty}\frac{T(r,\Delta_c^{(k)}f)}{T(r,\Delta_c^{(n)}f)}=1.$$

Proof. We omit the proof of Lemma 2.3 because it can be carried out in the similar lines of Lemma 2.2.

Lemma 2.9. *Let $f(z)$ is a transcendental meromorphic function of finite order and $\sum_{a\in\mathbb{C}}\delta(a,f)=1$ and $\delta(\infty,f)=1$, then for any α,*

$$\delta_{R(n)}^{(k)}=\underline{\lim}_{r\to+\infty}\frac{m(r,\alpha,\Delta_c^{(k)}f)}{T(r,\Delta_c^{(n)}f)}.$$

Proof. We have

$$\begin{aligned}
\delta_{R(n)}^{(k)} &= 1-\overline{\lim}_{r\to+\infty}\frac{N(r,\alpha,\Delta_c^{(k)}f)}{T(r,\Delta_c^{(n)}f}\\
&= 1-\overline{\lim}_{r\to+\infty}\frac{N(r,\alpha,\Delta_c^{(k)}f)}{T(r,\Delta_c^{(k)}f)}\lim_{r\to+\infty}\frac{T(r,\Delta_c^{(k)}f)}{T(r,\Delta_c^{(n)}f)}\\
&= 1-\overline{\lim}_{r\to+\infty}\frac{N(r,\alpha,\Delta_c^{(k)}f)}{T(r,\Delta_c^{(k)}f)}\\
&= \underline{\lim}_{r\to+\infty}\frac{m(r,\alpha,\Delta_c^{(k)}f)}{T(r,\Delta_c^{(k)}f)}\\
&= \underline{\lim}_{r\to+\infty}\frac{m(r,\alpha,\Delta_c^{(k)}f)}{T(r,\Delta_c^{(n)}f)}\lim_{r\to+\infty}\frac{T(r,\Delta_c^{(n)}f)}{T(r,\Delta_c^{(k)}f)}\\
&= \underline{\lim}_{r\to+\infty}\frac{m(r,\alpha,\Delta_c^{(k)}f)}{T(r,\Delta_c^{(n)}f)}.
\end{aligned}$$

Thus the lemma is established.

Lemma 2.10. *Let $f(z)$ is a transcendental meromorphic function of finite order and $\sum_{a\in\mathbb{C}}\delta(a,f)=1$ and $\delta(\infty,f)=1$, then for any α,*

$$\Delta_{R(n)}^{(k)}=\overline{\lim}_{r\to+\infty}\frac{m(r,\alpha,\Delta_c^{(k)}f)}{T(r,\Delta_c^{(n)}f)}.$$

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3 Main Results

In this section we present the main results of the paper are as follows

Theorem 3.1. *Let $f(z)$ is a transcendental meromorphic function of finite order such that $m(r, f) = S(r, f)$. If a, b and c are three distinct complex numbers, then for any two positive integer k and n*

$$\delta^{(0)}_{R(n)}(0, \Delta_c f) + \Delta^{(k)}_{R(n)}(\infty, \Delta^{(k)}_c f) + \delta^{(0)}_{R(n)}(c, \Delta_c f) \leq \Delta^{(0)}_{R(n)}(\infty, \Delta_c f) + 2\Delta^{(k)}_{R(n)}(0, \Delta^{(k)}_c f).$$

Proof. Let us consider the following identity

$$\frac{c}{f} = \left[\left(1 - \frac{f-c}{\Delta^{(k)}_c f}\frac{\Delta^{(k)}_c f}{f}\right)\left(\frac{\Delta^{(k)}_c f}{f-a}\frac{1}{\Delta^{(k)}_c f}\right)\right](f-a).$$

Since

$$m\left(r, \frac{1}{f}\right) \leq m\left(r, \frac{c}{f}\right) + O(1)$$

and

$$m(r, f-a) \leq m(r, f) + O(1),$$

then from the above identity we have

$$m\left(r, \frac{c}{f}\right) \leq m\left(r, \frac{f-c}{\Delta^{(k)}_c f}\right) + m\left(r, \frac{c}{\Delta^{(k)}_c f}\right) + m(r, f) + S(r, f).$$

Therefore

$$\begin{aligned} m\left(r, \frac{1}{f}\right) \leq\ & T\left(r, \frac{f-c}{\Delta^{(k)}_c f}\right) - N\left(r, \frac{f-c}{\Delta^{(k)}_c f}\right) + T\left(r, \frac{c}{\Delta^{(k)}_c f}\right) \\ & -N\left(r, \frac{c}{\Delta^{(k)}_c f}\right) + m(r, f) + S(r, f). \end{aligned} \tag{3.1}$$

Thus,

$$\begin{aligned} m\left(r, \frac{1}{f}\right) \leq\ & T\left(r, \frac{\Delta^{(k)}_c f}{f-c}\right) - N\left(r, \frac{f-c}{\Delta^{(k)}_c f}\right) + T\left(r, \Delta^{(k)}_c f\right) \\ & -N\left(r, \frac{c}{\Delta^{(k)}_c f}\right) + m(r, f) + S(r, f). \end{aligned}$$

Therefore

$$\begin{aligned} m\left(r, \frac{1}{f}\right) \leq\ & N\left(r, \frac{\Delta^{(k)}_c f}{f-c}\right) - N\left(r, \frac{f-c}{\Delta^{(k)}_c f}\right) \\ & -N\left(r, \frac{1}{\Delta^{(k)}_c f}\right) + T\left(r, \Delta^{(k)}_c f\right) + m(r, f) + S(r, f). \end{aligned} \tag{3.2}$$

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From (3.2) it follows that

$$m\left(r,\frac{1}{f}\right) \leq N\left(r,\Delta_c^{(k)}f\right)+N\left(r,\frac{1}{f-c}\right)-N\left(r,f-c\right)-N\left(r,\frac{1}{\Delta_c^{(k)}f}\right) -N\left(r,\frac{1}{\Delta_c^{(k)}f}\right)+T\left(r,\Delta_c^{(k)}f\right)+m(r,f)+S(r,f). \quad (3.3)$$

Applying the condition $m(r,f)=S(r,f)$ and from (3.4) it follows that

$$m\left(r,\frac{1}{f}\right) \leq N\left(r,\Delta_c^{(k)}f\right)+N\left(r,\frac{1}{f-c}\right)-N\left(r,f-c\right)-2N\left(r,\frac{1}{\Delta_c^{(k)}f}\right) +T\left(r,f^{(k)}\right)+S(r,f).$$

Implies

$$\varliminf_{r\to\infty}\frac{m\left(r,\frac{1}{f}\right)}{T(r,\Delta_c^{(n)}f)} \leq \varliminf_{r\to\infty}\frac{N\left(r,\Delta_c^{(k)}f\right)}{T(r,\Delta_c^{(n)}f)}+\varlimsup_{r\to\infty}\frac{N\left(r,\frac{1}{f-c}\right)}{T(r,\Delta_c^{(n)}f} -\varliminf_{r\to\infty}\frac{N\left(r,f\right)}{T(r,\Delta_c^{(n)}f}-2\varliminf_{r\to\infty}\frac{N\left(r,\frac{1}{\Delta_c^{(k)}f}\right)}{T(r,f^{(n)}\Delta_c^{(n)}f} +\varliminf_{r\to\infty}\frac{T\left(r,\Delta_c^{(k)}f\right)}{T(r,\Delta_c^{(n)}f}.$$

Therefore

$$\delta_{R(n)}^{(0)}(0,\Delta_c f) \leq [1-\Delta_{R(n)}^{(k)}(\infty,\Delta_c^{(k)}f)]+[1-\delta_{R(n)}^{(0)}(c,\Delta_c f)]-[1-\Delta_{R(n)}^{(0)}(\infty,\Delta_c f)] -2[1-\Delta_{R(n)}^{(k)}(0,\Delta_c^{(k)}f)]+1.$$

Hence

$$\delta_{R(n)}^{(0)}(0,\Delta_c f)+\Delta_{R(n)}^{(k)}(\infty,\Delta_c^{(k)}f)+\delta_{R(n)}^{(0)}(c,\Delta_c f)\leq\Delta_{R(n)}^{(0)}(\infty,\Delta_c f)+2\Delta_{R(n)}^{(k)}(0,\Delta_c^{(k)}f).$$

Theorem 3.2. *Let $f(z)$ is a transcendental meromorphic function of finite order such that $m(r,f)=S(r,f)$. If a and d are two distinct complex numbers, then for any two positive integer k and p with $0\leq k\leq p$*

$$\delta_{R(n)}^{(0)}(d,\Delta_c f)+\Delta_{R(n)}^{(p)}(\infty,\Delta_c^{(p)}f)+\delta_{R(n)}^{(k)}(a,\Delta_c^{(k)}f) \leq \Delta_{R(n)}^{(k)}(\infty,\Delta_c^{(k)}f)+\Delta_{R(n)}^{(p)}(0,\Delta_c^{(p)}f) +\Delta_{R(n)}^{(k)}(0,f),$$

where n is any positive integer.

Proof. Let us consider the following identity

$$\frac{1}{f-d}=\left[\frac{1}{a}\left(\frac{\Delta_c^{(k)}f}{f-a}-\frac{\Delta_c^{(k)}f-a}{\Delta_c^{(p)}f}.\frac{\Delta_c^{(p)}f}{f-a}\right)\left(\frac{\Delta_c^{(k)}f}{f-d}\frac{1}{\Delta_c^{(k)}f}\right)\right](f-a).$$

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Since $m(r, f-a) \le m(r, f) + O(1)$ and from the above identity, we have

$$m\left(r, \frac{1}{f-d}\right) \le m\left(r, \frac{\Delta_c^{(k)} f - a}{\Delta_c^{(p)} f}\right) + m\left(r, \frac{1}{\Delta_c^{(k)} f}\right) + m(r, f) + S(r, f). \quad (3.4)$$

From (3.4), we have

$$\begin{aligned} m\left(r, \frac{1}{f-d}\right) &\le T\left(r, \frac{\Delta_c^{(k)} f - a}{\Delta_c^{(p)} f}\right) - N\left(r, \frac{\Delta_c^{(k)} f - a}{\Delta_c^{(p)} f}\right) \\ &+ T\left(r, \frac{1}{\Delta_c^{(k)} f}\right) - N\left(r, \frac{1}{\Delta_c^{(k)} f}\right) + m(r, f) + S(r, f). \end{aligned}$$

Therefore

$$\begin{aligned} m\left(r, \frac{1}{f-d}\right) &\le T\left(r, \frac{\Delta_c^{(p)} f}{\Delta_c^{(k)} f - a}\right) - N\left(r, \frac{\Delta_c^{(k)} f - a}{\Delta_c^{(p)} f}\right) \\ &+ T\left(r, \Delta_c^{(k)} f\right) - N\left(r, \frac{1}{\Delta_c^{(k)} f}\right) + m(r, f) + S(r, f). \end{aligned}$$

Thus,

$$\begin{aligned} m\left(r, \frac{1}{f-d}\right) &\le N\left(r, \frac{\Delta_c^{(p)} f}{\Delta_c^{(k)} f - a}\right) - N\left(r, \frac{\Delta_c^{(k)} f - a}{\Delta_c^{(p)} f}\right) \\ &+T\left(r, \Delta_c^{(k)} f\right) - N\left(r, \frac{1}{\Delta_c^{(k)} f}\right) + m(r, f) + S(r, f), \end{aligned}$$

implies

$$\begin{aligned} m\left(r, \frac{1}{f-d}\right) &\le N\left(r, \Delta_c^{(p)} f\right) + N\left(r, \frac{1}{\Delta_c^{(k)} f - a}\right) - N\left(r, \Delta_c^{(k)} f - a\right) - N\left(r, \frac{1}{\Delta_c^{(p)} f}\right) \\ &+T\left(r, \Delta_c^{(k)} f\right) - N\left(r, \frac{1}{\Delta_c^{(k)} f}\right) + m(r, f) + S(r, f). \quad (3.5) \end{aligned}$$

Applying the condition $m(r, f) = S(r, f)$ and from (3.6), we have

$$\begin{aligned} m\left(r, \frac{1}{f-d}\right) &\le N\left(r, \Delta_c^{(p)} f\right) + N\left(r, \frac{1}{\Delta_c^{(k)} f - a}\right) - N\left(r, \Delta_c^{(k)} f - a\right) - N\left(r, \frac{1}{\Delta_c^{(p)} f}\right) \\ &+T\left(r, \Delta_c^{(k)} f\right) - N\left(r, \frac{1}{\Delta_c^{(k)} f}\right) + S(r, f). \end{aligned}$$

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Therefore

$$\begin{aligned}
\lim_{r\to\infty}\frac{m\left(r,\frac{1}{f-d}\right)}{T(r,\Delta_c^{(n)}f)} \leq\ & \lim_{r\to\infty}\frac{N\left(r,\Delta_c^{(p)}f\right)}{T(r,\Delta_c^{(n)}f)} + \overline{\lim_{r\to\infty}}\frac{N\left(r,\frac{1}{\Delta_c^{(k)}f-a}\right)}{T(r,\Delta_c^{(n)}f)} \\
& - \lim_{r\to\infty}\frac{N\left(r,\Delta_c^{(k)}f\right)}{T(r,\Delta_c^{(n)}f)} - \lim_{r\to\infty}\frac{N\left(r,\frac{1}{\Delta_c^{(p)}f}\right)}{T(r,\Delta_c^{(n)}f)} \\
& - \lim_{r\to\infty}\frac{N\left(r,\frac{1}{\Delta_c^{(k)}f}\right)}{T(r,\Delta_c^{(n)}f)} + \lim_{r\to\infty}\frac{T\left(r,\Delta_c^{(k)}f\right)}{T(r,\Delta_c^{(n)}f)}.
\end{aligned}$$

Implies

$$\begin{aligned}
&\delta_{R(n)}^{(0)}(d,\Delta_c f) \\
&\leq [1-\Delta_{R(n)}^{(p)}(\infty,\Delta_c^{(p)}f)] - [1-\Delta_{R(n)}^{(k)}(\infty,\Delta_c^{(k)}f)] - [1-\Delta_{R(n)}^{(p)}(0,\Delta_c^{(p)}f)] \\
&-[1-\Delta_{R(n)}^{(k)}(0,\Delta_c^{(k)}f)] + [1-\delta_{R(n)}^{(k)}(a,\Delta_c^{(k)}f)] + 1.
\end{aligned}$$

Hence

$$\begin{aligned}
&\delta_{R(n)}^{(0)}(d,\Delta_c f) + \Delta_{R(n)}^{(p)}(\infty,\Delta_c^{(p)}f) + \delta_{R(n)}^{(k)}(a,\Delta_c^{(k)}f) \\
&\leq \Delta_{R(n)}^{(k)}(\infty,\Delta_c^{(k)}f) + \Delta_{R(n)}^{(p)}(0,\Delta_c^{(p)}f) \\
&+\Delta_{R(n)}^{(k)}(0,\Delta_c^{(k)}f).
\end{aligned}$$

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Original Article

Value distribution of meromorphic functions and its uniqueness on Annuli

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Abstract
In this paper, we have invastigated several results on uniqueness of meromorphic functions on annuli.
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1 Introduction

In 2005, A. Ya. Khrystiyanyn and A. A. Kondratyuk have proposed on the Nevanlinna Theory for meromorphic functions on annuli (see [6,7]) and after this work others have done lot of work in this area (see [5], [12], [13]-[15]). In 2009, Cao and Yi [8] investigated the uniqueness of meromorphic functions sharing some values on annuli. In 2015, Yang Tan[2], Yang Tan and Yue Wang [1] proved some interesting results on the multiple values and uniqueness of algebroid functions on annuli and also others have proved several results for algebroid functions on annuli ([9], [11], [16], [18]-[26]). Thus it is interesting to consider the uniqueness problem of algebroid functions in multiply connected domains. By Doubly connected mapping theorem [10] each doubly connected domain is conformally equivalent to the annulus $\{z : r < |z| < R\}, 0 \leq r < R \leq +\infty$. We consider only two cases : $r = 0,\ R = +\infty$ simultaneously and $0 \leq r < R \leq +\infty$. In the latter case the homothety $z \mapsto \frac{z}{rR}$ reduces the given domain to the annulus $\mathbb{A} = \mathbb{A}(R_0) = \mathbb{A}\left(\frac{1}{R_0}, R_0\right) = \left\{z : \frac{1}{R_0} < |z| < R_0\right\}$, where $R_0 = \sqrt{\frac{R}{r}}$. Thus, in both cases every annulus is invariant with respect to the inversion $z \mapsto \frac{1}{z}$.

2 Basic notations in the Nevanlinna theory on annuli

In this paper, a meromorphic function always mean a function which is meromorphic in $\mathbb{A}(R_0)$, where $1 < R_0 \leq +\infty$. Let $f(z)$ and $g(z)$ be non constant meromorphic in $\mathbb{A}(R_0)$, where $1 < R_0 \leq +\infty$, $a \in \overline{\mathbb{C}}$. We say that f and g share the value a CM if $f(z) - a$ and $g(z) - a$ have the same zeros with the same multiplicities. We shall use standard notations of value distribution theory in annuli, $T_0(R, f)$, $m_0(R, f)$, $N_0(R, f)$, $\overline{N}_0(R, f)$,...(see[6],[7])

3 Main Results

Let $f(z)$ be a meromorphic function on the annulus $\mathbb{A} = \left\{z : \frac{1}{R_0} < |z| < R_0\right\}$, where $1 < R < R_0 \leq +\infty$, and $'a'$ be a complex number in the extende complex plane

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$\overline{\mathbb{C}} = \mathbb{C} \cup \{\infty\}$. Write $E(a, f) = \{z \in \mathbb{A} : f(z) - a = 0\}$, where each zero with multiplicity m is counted m times. If we ignore the multiplicity, then the set is denoted by $\overline{E}(a, f)$. We use $\overline{E}_{k)}(a, f)$ to denote the set of zeros of $f - a$ with multiplicities no greater than k, in which each zero is counted only once. Let f and g be two be two transcedental meromorphic functions on the annulus $\mathbb{A} = \left\{z : \frac{1}{R_0} < |z| < R_0\right\}$, where $1 < R_0 \leq +\infty$ have the same zeros with same multiplicities, we denote this by $f = a \rightleftharpoons g = a$.

The following lemmas will be needed in the proof of Theorem 2.

Lemma 3.1. *Let $f(z)$ be a transcedental meromorphic function on the annulus $\mathbb{A} = \left\{z : \frac{1}{R_0} < |z| < R_0\right\}$, where $1 < R < R_0 \leq +\infty$ and let n be a non-negative integer. Then*

$$N_0\left(r, \frac{1}{f^{(n)}}\right) < T_0(r, f^{(n)}) - T_0(r, f) + N_0\left(r, \frac{1}{f}\right) + S_0((r, f).$$

We note that

$$\begin{aligned} m_0\left(r, \frac{1}{f}\right) &\leq m_0\left(r, \frac{1}{f^{(n)}}\right) + m_0\left(r, \frac{f^{(n)}}{f}\right) \\ &= m_0\left(r, \frac{1}{f^{(n)}}\right) + S_0(r, f). \end{aligned} \tag{3.1}$$

By the first fundamental theorem on annuli, we have from (3.1)

$$T_0(r, f) - N_0\left(r, \frac{1}{f}\right) \leq T_0(r, f^{(n)}) - N_0\left(r, \frac{1}{f^{(n)}}\right) + S_0(r, f)$$

and hence

$$N_0\left(r, \frac{1}{f^{(n)}}\right) < T_0(r, f^{(n)}) - T_0(r, f) + N_0\left(r, \frac{1}{f}\right) + S_0((r, f), \tag{3.2}$$

which proves Lemma 1.

Lemma 3.2. *Let $f(z)$ be a transcedental meromorphic function on the annulus $\mathbb{A} = \left\{z : \frac{1}{R_0} < |z| < R_0\right\}$, where $1 < R < R_0 \leq +\infty$ and let n be a non-negative integer. Then*

$$N_0\left(r, \frac{1}{f^{(n)}}\right) < N_0\left(r, \frac{1}{f}\right) + n\overline{N}_0(r, f) + S_0((r, f).$$

Proof. By Lemma 1, we have

$$N_0\left(r, \frac{1}{f^{(n)}}\right) < T_0(r, f^{(n)}) - T_0(r, f) + N_0\left(r, \frac{1}{f}\right) + S_0((r, f), \tag{3.3}$$

By Milloux basic result (see [15]), we have

$$T_0(r, f^{(n)}) < T_0(r, f) + n\overline{N}_0(r, f) + S_0(r, f). \tag{3.4}$$

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From (3.3) and (3.4) we obtain

$$N_0\left(r,\frac{1}{f^{(n)}}\right) < N_0\left(r,\frac{1}{f}\right) + n\overline{N}_0(r,f) + S_0((r,f).$$

Which proves Lemma 2.

Lemma 3.3. *Let $f(z)$ and $g(z)$ be two transcedental meromorphic functions in $\mathbb{A}(R_0)$, where $1 < R_0 \le +\infty$, n be a positive integer. If $f=0 \rightleftarrows g=0$, $f=\infty \rightleftarrows g=\infty$, $f^{(n)}=1 \rightleftarrows g^{(n)}=1$ and $\overline{\lim\limits_{r\to\infty}} \dfrac{2N_0\left(r,\frac{1}{f}\right)+(n+2)\overline{N}_0(r,f)}{T_0(r,f)} < 1$. Then*

$$T_0(r,f) = O(T_0(r,g))\ (r \notin E).$$

Proof. By Milloux's basic result (see [15]), we have

$$T_0(r,g) < N_0\left(r,\frac{1}{g}\right) + \overline{N}_0(r,g) + N_0\left(r,\frac{1}{g^{(n)}-1}\right) + S_0(r,g). \tag{3.5}$$

We note that

$$N_0\left(r,\frac{1}{g}\right) - N_0\left(r,\frac{1}{f}\right) \le T_0(r,f) + O(1), \tag{3.6}$$

$$\overline{N}_0(r,g) = \overline{N}_0(r,f) \le T_0(r,f) \tag{3.7}$$

and

$$\begin{aligned} N_0\left(r,\frac{1}{g^{(n)}-1}\right) &= N_0\left(r,\frac{1}{f^{(n)}-1}\right) \le T_0(r,f^{(n)}) + O(1), \\ &< (n+1)T_0(r,f) + S_0(r,f). \end{aligned} \tag{3.8}$$

From (3.5) and (3.8) we obtain

$$T_0(r,g) < (n+3)T_0(r,f) + S_0(r,f) + S_0(r,g).$$

Similarly

$$T_0(r,f) < (n+3)T_0(r,g) + S_0(r,f) + S_0(r,g)$$

and hence

$$(1+o(1))T_0(r,g) < (n+3+o(1))T_0(r,f)\ (r \notin E).$$

That is,

$$T_0(r,f) = O(T_0(r,g))\ (r \notin E).$$

Which completes the proof of Lemma 3.

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Lemma 3.4. *Let $f(z)$ and $g(z)$ be two transcedental meromorphic functions in $\mathbb{A}(R_0)$, where $1 < R_0 \leq +\infty$, n be a positive integer. If $f = 0 \rightleftarrows g = 0$, $f = \infty \rightleftarrows g = \infty$, $f^{(n)} = 1 \rightleftarrows g^{(n)} = 1$ and $\overline{\lim\limits_{r\to\infty}} \dfrac{2N_0\left(r, \frac{1}{f}\right) + (n+2)\overline{N}_0(r,f)}{T_0(r,f)} < 1$. Then*

$$N_0\left(r, \frac{1}{f^{(n)}}\right) + N_0\left(r, \frac{1}{g^{(n)}}\right) + 2\overline{N}_0(r,f) < T_0(r, f^{(n)}) - \lambda T_0(r,f) + S_0(r,f),$$

where $\lambda > 0$

Proof. Suppose that

$$\overline{\lim_{r\to\infty}} \frac{2N_0\left(r, \frac{1}{f}\right) + (n+2)\overline{N}_0(r,f)}{T_0(r,f)} = 1 - \lambda. \tag{3.9}$$

By hypothesis of Lemma 4 we know $\lambda > 0$, then we have

$$S_0(r,g) = S_0(r,f). \tag{3.10}$$

From Lemma 2, (3.6), (3.7), (3.10) we obtain

$$N_0\left(r, \frac{1}{g^{(n)}}\right) < N_0\left(r, \frac{1}{f}\right) + n\overline{N}_0(r,f) + S_0(r,f). \tag{3.11}$$

From (3.9) we have

$$2N_0\left(r, \frac{1}{f}\right) + (n+2)\overline{N}_0(r,f) < (1-\lambda)T_0(r,f) + S_0(r,f). \tag{3.12}$$

From Lemma 1, (3.11) and (3.12), we get

$$N_0\left(r, \frac{1}{f^{(n)}}\right) + N_0\left(r, \frac{1}{g^{(n)}}\right) + 2\overline{N}_0(r,f) < T_0(r, f^{(n)}) - \lambda T_0(r,f) + S_0(r,f), \tag{3.13}$$

which proves Lemma 4.

Lemma 3.5. *Let $f_1(z)$ and $f_2(z)$ be two transcedental meromorphic functions on the annulus $\mathbb{A} = \left\{z : \frac{1}{R_0} < |z| < R_0\right\}$, where $1 < R_0 \leq +\infty$ and let c_1, c_2 and c_3 be three non zero constants. If $c_1 f_1 + c_2 f_2 + c_3 f_3$, then*

$$T_0(r, f_1) < N_0\left(r, \frac{1}{f_1}\right) + N_0\left(r, \frac{1}{f_2}\right) + \overline{N}_0(r, f_1) + S_0(r, f_1).$$

Proof. By second fundamental theorem on annuli Lemma 5 follows immediately.

Lemma 3.6. [33] *Suppose that $f_1(z), f_2(z), \ldots, f_n(z)$ are linearly independent meromorphic functions in $\mathbb{A}(R_0)$, where $1 < R_0 \leq +\infty$ satisfying the following identity*

$$\sum_{j=1}^{n} f_j \equiv 1$$

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Then for $1 \leq j \leq n$, we have

$$T_0(R,f) \leq \sum_{k=1}^{n} N_0\left(R, \frac{1}{f_k}\right) + N_0(R, f_j) + N_0(R, D) - \sum_{k=1}^{n} N_0(R, f_k) - N_0\left(R, \frac{1}{D}\right) + S(R,f)$$

Where D is the Wronskian determinant $W(f_1, f_2, \ldots, f_n)$, $S(r,f) = o(T_0(R,f))$ and $T_0(R,f) = max_{1 \leq k \leq n}\{T_0(R, f_k)\}$, for every R such that $1 < R < R_0$, $R \notin E$ and E is the set of finite linear measure.

Lemma 3.7. *Let $f(z)$ and $g(z)$ be two transcedental meromorphic functions in $\mathbb{A}(R_0)$, where $1 < R_0 \leq +\infty$, n be a positive integer. If $f = 0 \rightleftarrows g = 0$, $f = \infty \rightleftarrows g = \infty$, $f^{(n)} = 1 \rightleftarrows g^{(n)} = 1$ and $\overline{\lim_{r\to\infty}} \dfrac{2N_0\left(r, \frac{1}{f}\right) + (n+2)\overline{N}_0(r,f)}{T_0(r,f)} < 1$, $f^{(n)} \equiv g^{(n)}$, then $f \equiv g$.*

Proof. Suppose that $f \not\equiv g$. From $f^{(n)} \equiv g^{(n)}$, we have

$$f(z) = g(z) + p(z),$$

where $p(z)(\not\equiv 0)$ is a polynomial of degree at most $n-1$.
From the hypothesis Lemma 7 we know that $f(z)$ be two transcedental meromorphic functions on the annulus $\mathbb{A} = \left\{z : \frac{1}{R_0} < |z| < R_0\right\}$, where $1 < R_0 \leq +\infty$. Thus we get

$$T_0(r,p) = o(T_0(r,f))$$

and

$$T_0(r,g) = (1 + o()1)T_0(r,f). \tag{3.14}$$

By the second fundamental theorem on annuli, we have

$$\begin{aligned} T_0(r,f) &< N_0\left(r, \frac{1}{f}\right) + N_0\left(r, \frac{1}{f-p}\right) + \overline{N}_0(r,f) + S_0(r,f) \\ &= N_0\left(r, \frac{1}{f}\right) + N_0\left(r, \frac{1}{g}\right) + \overline{N}_0(r,f) + S_0(r,f) \\ &= 2N_0\left(r, \frac{1}{f}\right) + \overline{N}_0(r,f) + S_0(r,f) \end{aligned} \tag{3.15}$$

From (3.11) and (3.15) we obtain

$$\lambda T_0(r,f) < S_0(r,f). \tag{3.16}$$

which is impossible. This proves that $f \equiv g$.

We now prove our main result below which is an analog of a result on the plane $\mathbb{C}$ obtained by Hong Xun Yi [32].

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Theorem 3.1. *Let $f(z)$ and $g(z)$ be two transcedental meromorphic functions in $\mathbb{A}(R_0)$, where $1 < R_0 \leq +\infty$, n be a positive integer. If*

$$f = 0 \rightleftarrows g = 0, \quad f = \infty \rightleftarrows g = \infty, \quad f^{(n)} = 1 \rightleftarrows g^{(n)} = 1 \tag{3.17}$$

and

$$\varlimsup_{r\to\infty} \frac{2N_0\left(r, \frac{1}{f}\right) + (n+2)\overline{N}_0(r, f)}{T_0(r, f)} < 1. \tag{3.18}$$

Then $f \equiv g$ or $f^{(n)}g^{(n)} \equiv 1$.

Proof. From (3.36)

$$f^{(n)} - 1 = e^{(\alpha)}(g^{(n)} - 1) \tag{3.19}$$

where α is an entire function.
Let $f_1 = f^{(n)}$, $f_2 = e^{\alpha}$, $f_3 = -e^{\alpha}g^{(n)}$, and $T_0(r)$ denotes the maximum of $T_0(r, f_i)$, $i = 1, 2, 3$. From (3.19) we obtain

$$\sum_{i=1}^{3} f_i \equiv 1 \tag{3.20}$$

and

$$\sum_{i=1}^{3} N_0\left(r, \frac{1}{f_i}\right) = N_0\left(r, \frac{1}{f^{(n)}}\right) + N_0\left(r, \frac{1}{g^{(n)}}\right). \tag{3.21}$$

obviously

$$T_0(r, f^{(n)}) = O(T_0(r, f)) \ (r \notin E), \tag{3.22}$$

$$T_0(r, g^{(n)}) = O(T_0(r, g)) \ (r \notin E), \tag{3.23}$$

By Lemma 3 and (3.23) we know

$$T_0(r, g^{(n)}) = O(T_0(r, f)) \ (r \notin E), \tag{3.24}$$

From (3.19), (3.22) and (3.24) we obtain

$$T_0(r, f_i) = O(T_0(r, f)) \ (r \notin E),$$

that is

$$T_0(r) = O(T_0(r, f)) \ (r \notin E), \tag{3.25}$$

Suppose neither f_2 nor f_3 are constants. If f_1, f_2 and f_3 are linearly independent, by Lemma 6 and (3.25), we have

$$T_0(r, f_i) < \sum_{i=1}^{3} N_0\left(r, \frac{1}{f_i}\right) + N_0(r, D) - N_0(r, f_2) - N_0(r, f_3) + S_0(r, f), \tag{3.26}$$

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where

$$D = \begin{vmatrix} f_1 & f_2 & f_3 \\ f_1' & f_2' & f_3' \\ f_1'' & f_2'' & f_3'' \end{vmatrix} \tag{3.27}$$

From (3.20) and (3.27), we get

$$D = \begin{vmatrix} f_2' & f_3' \\ f_2'' & f_3'' \end{vmatrix}$$

and hence

$$\begin{aligned} N_0(r, D) - N_0(r, f_2) - N_0(r, f_3) &\leq N_0(r, g^{(n+2)}) - N_0(r, g^{(n)}) \\ &= 2\overline{N}_0(r, g) = 2\overline{N}_0(r, f). \end{aligned} \tag{3.28}$$

From (3.21), (3.26) and (3.28) we obtain

$$T_0(r, f^{(n)}) < N_0\left(r, \frac{1}{f^{(n)}}\right) + N_0\left(r, \frac{1}{g^{(n)}}\right) + 2\overline{N}_0(r, f) + S_0(r, f). \tag{3.29}$$

By Lemma 4 and (3.29) we have

$$T_0(r, f^{(n)}) < T_0(r, f^{(n)}) - \lambda T_0(r, f) + S_0(r, f)$$

Thus we obtain

$$\lambda T_0(r, f) < S_0(r, f),$$

which is impossible.
If f_1, f_2 and f_3 are linearly dependent, there exist three constants $(c_1, c_2, c_3) \neq (0, 0, 0)$ such that

$$c_1 f_1 + c_2 f_2 + c_3 f_3 \equiv 0. \tag{3.30}$$

Assume $c_1 = 0$. From (3.20), (3.30) we have

$$f_1 + \left(1 - \frac{c_3}{c_2}\right) f_3 = 1. \tag{3.31}$$

By Lemma 5 and (3.31)

$$T_0(r, f_1) < N_0\left(r, \frac{1}{f_1}\right) + N_0\left(r, \frac{1}{f_3}\right) \overline{N}_0(r, f_1) + S_0(r, f).$$

That is

$$T_0(r, f^{(n)}) < N_0\left(r, \frac{1}{f^{(n)}}\right) + N_0\left(r, \frac{1}{g^{(n)}}\right) \overline{N}_0(r, f) + S_0(r, f). \tag{3.32}$$

By Lemma 4 and (3.32) we get

$$\lambda T_0(r, f) < S_0(r, f),$$

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which is impossible.
Assume that $c_1 \neq 0$. From (3.30) we know $(c_2, c_3) \neq (0, 0)$. We may suppose without loss of generality that $c_2 \neq 0$. By (3.20), (6.14) and the nonconstancy of f_2, f_3

$$\left(1 - \frac{c_2}{c_1}\right) f_2 + \left(1 - \frac{c_3}{c_1}\right) f_3 = 1 \tag{3.33}$$

and $c_1 \neq c_2$, $c_1 \neq c_3$. From (3.20) and (3.33), we get

$$f_1 + \frac{c_3 - c_2}{c_1 - c_2} f_3 = \frac{c_2}{c_2 - c_1}. \tag{3.34}$$

By Lemma 5 and (3.34) we obtain

$$T_0(r, f_1) < N_0\left(r, \frac{1}{f_1}\right) + N_0\left(r, \frac{1}{f_3}\right) \overline{N}_0(r, f_1) + S_0(r, f).$$

giving a contradiction as before.
Suppose $f_2 \equiv c$. If $c \neq 1$, from (3.20) we have

$$f_1 + f_3 = 1 - c. \tag{3.35}$$

By Lemma 5 and (3.35) we obtain

$$T_0(r, f_1) < N_0\left(r, \frac{1}{f_1}\right) + N_0\left(r, \frac{1}{f_3}\right) \overline{N}_0(r, f_1) + S_0(r, f).$$

giving a contradiction as before.
Therefore $c = 1$. From (3.19) we get $f^{(n)} \equiv g^{(n)}$. By Lemma 7 we obtain $f \equiv g$. Suppose that $f_3 \equiv c$. In a similar manner we get $f_3 \equiv 1$. From (3.19) we obtain $g^{(n)} = -e^{-\alpha}$, $f^{(n)} = -e^{\alpha}$ and hence $f^{(n)}g^{(n)} \equiv 1$.
This completes the proof of Theorem 2.

From Theorem 2 we immediately obtain the following corollaries **Corollary 1.** Let $f(z)$ and $g(z)$ be two transcedental meromorphic functions in $\mathbb{A}(R_0)$, where $1 < R_0 \leq +\infty$, n be a positive integer. If

$$f = 0 \rightleftarrows g = 0, \quad f = \infty \rightleftarrows g = \infty, \quad f^{(n)} = 1 \rightleftarrows g^{(n)} = 1$$

and

$$2\delta_0(0, f) + (n + 2)\Theta_0(\infty, f) > n + 3.$$

Then $f \equiv g$ or $f^{(n)}g^{(n)} \equiv 1$.

Corollary 2. Let $f(z)$ and $g(z)$ be two transcedental meromorphic functions in $\mathbb{A}(R_0)$, where $1 < R_0 \leq +\infty$, n be a positive integer. If

$$f = 0 \rightleftarrows g = 0, \quad f = \infty \rightleftarrows g = \infty, \quad f = 1 \rightleftarrows g = 1$$

and

$$\overline{\lim_{r\to\infty}} \frac{N_0\left(r,\frac{1}{f}\right)+(\frac{n}{2}+1)\overline{N}_0(r,f)}{T_0(r,f)} < \frac{1}{2}.$$

Then $f \equiv g$ or $f.g \equiv 1$.

Corollary 3. Let $f(z)$ and $g(z)$ be two transcedental meromorphic functions in $\mathbb{A}(R_0)$, where $1 < R_0 \leq +\infty$, n be a positive integer. If

$$f = 0 \rightleftarrows g = 0, \quad f^{(n)} = 1 \rightleftarrows g^{(n)} = 1$$

and

$$\delta_0(0, f) > \frac{1}{2}.$$

Then $f \equiv g$ or $f^{(n)}g^{(n)} \equiv 1$.

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Original Article

Value distribution for nth difference operator of meromorphic functions with relative (k; n) Valiron defect

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Abstract

In this paper, we study and compare the relation between relative (k;n) Valiron defect with the relative Nevanlinna defect for higher order exact difference of f(z), where k and n are both non negative integers.

Keywords: *Nevanlinna theory, Meromorphic functions, Valiron defect and Nevan linna defect.*

1 Introduction and results

Let $f(z)$ be a meromorphic function in the complex plane $\mathbb{C}$. We are using the notations of Nevanlinna theory of meromorphic functions (*see* [23]) such as,

$$T(r,f),\ m(r,f),\ N(r,f),\ m(r,a) = m\left(r, \frac{1}{f-a}\right),\ N(r,a) = N\left(r, \frac{1}{f-a}\right)$$

etc. A meromorphic function $a(z)$ is said to be a small function of f, if $T(r,a) = S(r,f)$, where $S(r,f) = o(T(r,f))$, as $r \to \infty$, without ristriction if $f(z)$ is of finite order and otherwise except possibly for a set of values of r of finite linear measure.

For a meromorphic function $f(z)$ and a nonzero constant c, $n \in \mathbb{N}$ we define its shipts by $f(z+c)$ and its difference operator by

$$\Delta_c f(z) = f(z+c) - f(z)$$

and

$$\Delta_c^n f(z) = \sum_{j=0}^{n} \binom{n}{j} (-1)^{n-j} f(z+jc),$$

where

$$\binom{n}{j} = \frac{n!}{j!(n-j)!}$$

If in the above inequality, equality holds, then we say that f has maximal deficiency sum.
The order ρ_f of a meromorphic function is defined as follows

$$\rho_f = \overline{\lim_{r\to\infty}} \frac{\log T(r,f)}{\log r}.$$

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If $\rho_f < \infty$, then f is of finite order.

The Nevanlinna defect $\delta(a, f)$ and Valiron defect $\Delta(a, f)$ of a for meromorphic function are respectively defined as follows

$$\delta(a, f) = \lim_{r\to+\infty} \frac{m(r, a, f)}{T(r, f)} = \overline{\lim_{r\to+\infty}} \frac{N(r, a, f)}{T(r, f)}$$

and

$$\Delta(a, f) = \lim_{r\to+\infty} \frac{m(r, a, f)}{T(r, f)} = \overline{\lim_{r\to+\infty}} \frac{N(r, a, f)}{T(r, f)}.$$

The relative Nevanlinna defect of α for $\Delta_c f$ with respect to $f^{(k)}$ is defined as follows

$$\delta_R^{(k)}(a, \Delta_c^{(k)} f) = \lim_{r\to+\infty} \frac{m(r, \alpha, \Delta_c^{(k)} f)}{T(r, f)} = \overline{\lim_{r\to+\infty}} \frac{N(r, \alpha, \Delta_c^{(k)} f)}{T(r, f)},$$

for k=1,2,3,...

The relative (k, n) Nevanlinna defect of α for $\Delta_c f$ with respect to $f^{(k)}$ for $k = 1, 2, 3, \ldots$ and $n = 0, 1, 2, 3, \ldots$ is defined as follows

$$\delta_{R(n)}^{(k)}(\alpha, \Delta_c^{(k)} f) = \lim_{r\to+\infty} \frac{m(r, \alpha, \Delta_c^{(k)} f)}{T(r, \Delta_c^{(n)} f)} = \overline{\lim_{r\to+\infty}} \frac{N(r, \alpha, \Delta_c^{(k)} f)}{T(r, \Delta_c^{(n)} f)}$$

and the relative (k, n) Valiron defect of α for with respect to $f^{(k)}$ for $k = 1, 2, 3, \ldots$ and $n = 0, 1, 2, 3, \ldots$ is defined as follows

$$\Delta_{R(n)}^{(k)}(\alpha, \Delta_c^{(k)} f) = \overline{\lim_{r\to+\infty}} \frac{m(r, \alpha, \Delta_c^{(k)} f)}{T(r, \Delta_c^{(n)} f)} = \lim_{r\to+\infty} \frac{N(r, \alpha, \Delta_c^{(k)} f)}{T(r, \Delta_c^{(n)} f)}.$$

The **Valiron-Mo'honko identity** says that: If the function $R(z, f)$ is rational function in f and has co-efficients as small meromorphic functions, then

$$T(r, R(z, f)) = deg_f(R)T(r, f) + S(r, f). \tag{1.1}$$

2 Some Lemmas

We need the following Lemmas to prove our results.

Lemma 2.1. [13] *Let $f(z)$ be a transcendental meromorphic function of order $\sigma(< 1)$, and let c be a non-zero complex number. Then*

$$m\left(r, \frac{f(z+c)}{f(z)}\right) = o(T(r, f)) = S(r, f).$$

Lemma 2.2. [13] *Let $f(z)$ be a transcendental meromorphic function of order $\sigma(< 1)$, and let c be a non-zero complex number. Then*

$$m\left(r, \frac{\Delta_c^n f(z)}{f(z)}\right) = o(T(r, f)) = S(r, f).$$

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Lemma 2.3. [13] *Let $f(z)$ be a transcendental meromorphic function of order less than one and let c be a non-zero complex number. Then*

$$N(r, f(z+c)) = N(r, f) + S(r, f).$$

Lemma 2.4. [13] *Let $f(z)$ be a transcendental meromorphic function of order less than one and let c be a non-zero complex number. Then*

$$N(r, \Delta_c^n f(z)) \leq \sum_{j=0}^{n} \binom{n}{j} N(r, f) + S(r, f).$$

Lemma 2.5. [13] *Let $f(z)$ be a transcendental meromorphic function of order less than one and let c be a non-zero complex number and n be a non negative integer. Then*

$$N(r, f) \leq N(r, \Delta_c^n f(z)).$$

In 2019, Bhoosnurmath ([13])proved the following theorem

Theorem 2.1. *Suppose that $f(z)$ is a transcendental meromorphic function of order less than one. Then we have*

$$\sum_{a\in\mathbb{C}} \delta(a, f) \leq \underline{\lim}_{r\to\infty} \frac{T(r, \Delta_c^n f)}{T(r, f)} \leq \overline{\lim}_{r\to\infty} \frac{T(r, \Delta_c^n f)}{T(r, f)} \leq (n+1) - n\delta(\infty, f). \tag{2.1}$$

(i) For $n = 1$ with maximal deficiency sum and $\sum_{a\in\mathbb{C}} \delta(a, f) = \alpha$, $(1 \leq \alpha \leq 2)$

$$T(r, \Delta_c f) \sim \alpha T(r, f), \quad as \quad r \to \infty.$$

(ii) For $n \geq 1$ with $\sum_{a\in\mathbb{C}} \delta(a, f) = 1$ and $\delta(\infty, f) = 1$,

$$\lim_{r\to\infty} \frac{T(r, \Delta_c^n f)}{T(r, f)} = 1.$$

Theorem 2.2. [22] *Let $f(z)$ is a transcendental meromorphic function of finite order less than one and $\delta(\infty, f) = 1$, then*

$$\sum_{a\in\mathbb{C}} \delta(a, f) \leq \delta(0, \Delta_c f).$$

Here we prove some lemmas which will be useful to prove our main results

Lemma 2.6. *Let $f(z)$ is a transcendental meromorphic function of finite order and $\sum_{a\in\mathbb{C}} \delta(a, f) = 1$ and $\delta(\infty, f) = 1$, then*

$$\lim_{r\to+\infty} \frac{T(r, \Delta_c f)}{T(r, f)} = 1.$$

Proof. We omit the proof of Lemma 2.1 because it can be carried out in the similar lines of Theorem 2.1.

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Lemma 2.7. *Let $f(z)$ is a transcendental meromorphic function of finite order and $\sum_{a\in\mathbb{C}} \delta(a,f) = 1$ and $\delta(\infty, f) = 1$, then for a non-negative integer k,*

$$\lim_{r\to+\infty} \frac{T(r,\Delta_c^{(k)} f)}{T(r,f)} = 1.$$

Proof. We omit the proof of Lemma 2.2 because it can be carried out in the similar lines of Lemma 2.1.

Lemma 2.8. *Let $f(z)$ is a transcendental meromorphic function of finite order and $\sum_{a\in\mathbb{C}} \delta(a,f) = 1$ and $\delta(\infty, f) = 1$, then for a non-negative integer k,*

$$\lim_{r\to+\infty} \frac{T(r,\Delta_c^{(k)} f)}{T(r,\Delta_c^{(n)} f)} = 1.$$

Proof. We omit the proof of Lemma 2.3 because it can be carried out in the similar lines of Lemma 2.2.

Lemma 2.9. *Let $f(z)$ is a transcendental meromorphic function of finite order and $\sum_{a\in\mathbb{C}} \delta(a,f) = 1$ and $\delta(\infty, f) = 1$, then for any α,*

$$\delta_{R(n)}^{(k)} = \underline{\lim}_{r\to+\infty} \frac{m(r,\alpha,\Delta_c^{(k)} f)}{T(r,\Delta_c^{(n)} f)}.$$

Proof. We have

$$\begin{aligned}
\delta_{R(n)}^{(k)} &= 1 - \overline{\lim}_{r\to+\infty} \frac{N(r,\alpha,\Delta_c^{(k)} f)}{T(r,\Delta_c^{(n)} f} \\
&= 1 - \overline{\lim}_{r\to+\infty} \frac{N(r,\alpha,\Delta_c^{(k)} f)}{T(r,\Delta_c^{(k)} f)} \lim_{r\to+\infty} \frac{T(r,\Delta_c^{(k)} f)}{T(r,\Delta_c^{(n)} f)} \\
&= 1 - \overline{\lim}_{r\to+\infty} \frac{N(r,\alpha,\Delta_c^{(k)} f)}{T(r,\Delta_c^{(k)} f)} \\
&= \underline{\lim}_{r\to+\infty} \frac{m(r,\alpha,\Delta_c^{(k)} f)}{T(r,\Delta_c^{(k)} f)} \\
&= \underline{\lim}_{r\to+\infty} \frac{m(r,\alpha,\Delta_c^{(k)} f)}{T(r,\Delta_c^{(n)} f)} \lim_{r\to+\infty} \frac{T(r,\Delta_c^{(n)} f)}{T(r,\Delta_c^{(k)} f)} \\
&= \underline{\lim}_{r\to+\infty} \frac{m(r,\alpha,\Delta_c^{(k)} f)}{T(r,\Delta_c^{(n)} f)}.
\end{aligned}$$

Thus the lemma is established.

Lemma 2.10. *Let $f(z)$ is a transcendental meromorphic function of finite order and $\sum_{a\in\mathbb{C}} \delta(a,f) = 1$ and $\delta(\infty, f) = 1$, then for any α,*

$$\Delta_{R(n)}^{(k)} = \overline{\lim}_{r\to+\infty} \frac{m(r,\alpha,\Delta_c^{(k)} f)}{T(r,\Delta_c^{(n)} f)}.$$

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3 Main Results

In this section we present the main results of the paper are as follows

Theorem 3.1. *Let $f(z)$ is a transcendental meromorphic function of finite order such that $m(r,f) = S(r,f)$. If a, b and c are three distinct complex numbers, then for any two positive integer k and n*

$$\begin{aligned}&3\delta^{(0)}_{R(n)}(a,\Delta_c f) + 2\delta^{(0)}_{R(n)}(b,\Delta_c f) + 3\delta^{(0)}_{R(n)}(c,\Delta_c f) + 5\Delta^{(0)}_{R(n)}(\infty,\Delta_c f)\\ &\leq 5\Delta^{(k)}_{R(n)}(\infty,\Delta^{(k)}_c f) + 5\Delta^{(k)}_{R(n)}(0,\Delta^{(k)}_c f).\end{aligned}$$

Proof. For any positive integer k, let us consider the following identity

$$\frac{b-a}{f-a} = \left[\frac{\Delta^{(k)}_c f}{f-a}\left(\frac{f-a}{\Delta^{(k)}_c f} - \frac{f-b}{\Delta^{(k)}_c f}\right) - \frac{f-c}{\Delta^{(k)}_c f}.\frac{\Delta^{(k)}_c f}{f}.\frac{\Delta^{(k)}_c f}{f-a}\left(\frac{f-a}{\Delta^{(k)}_c f} - \frac{f-b}{\Delta^{(k)}_c f}\right)\right]\frac{f}{c}$$

Since

$$m\left(r,\frac{1}{f-a}\right) \leq m\left(r,\frac{b-a}{f-a}\right) + O(1)$$

and

$$m\left(r,\frac{f}{c}\right) \leq m(r,f) + O(1).$$

From above identity, we get

$$\begin{aligned}m\left(r,\frac{b-a}{f-a}\right) \;\leq\;& m\left(r,\frac{f-a}{\Delta^{(k)}_c f}\right) + m\left(r,\frac{f-b}{\Delta^{(k)}_c f}\right) + m\left(r,\frac{f-c}{\Delta^{(k)}_c f}\right)\\ &+m\left(r,\frac{f-a}{\Delta^{(k)}_c f}\right) + m\left(r,\frac{f-b}{\Delta^{(k)}_c f}\right) + m\left(r,\frac{f}{c}\right) + S(r,f),\end{aligned}$$

implies

$$\begin{aligned}m\left(r,\frac{1}{f-a}\right) \;\leq\;& 2m\left(r,\frac{f-a}{\Delta^{(k)}_c f}\right) + 2m\left(r,\frac{f-b}{\Delta^{(k)}_c f}\right) + m\left(r,\frac{f-c}{\Delta^{(k)}_c f}\right)\\ &+m(r,f) + S(r,f).\end{aligned}$$

From above equation, we have

$$\begin{aligned}m\left(r,\frac{1}{f-a}\right) \;\leq\;& 2T\left(r,\frac{f-a}{\Delta^{(k)}_c f}\right) - 2N\left(r,\frac{f-a}{\Delta c^{(k)} f}\right)\\ &+2T\left(r,\frac{f-b}{\Delta^{(k)}_c f}\right) - 2N\left(r,\frac{f-b}{\Delta^{(k)}_c f}\right)\\ &+T\left(r,\frac{f-c}{\Delta^{(k)}_c f}\right) - N\left(r,\frac{f-c}{\Delta^{(k)}_c f}\right)\\ &+m(r,f) + S(r,f). \qquad (3.1)\end{aligned}$$

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By Lemma 2.8 and Lemma 2.9, it follows from (3.1) that

$$\begin{aligned} m\left(r,\frac{1}{f-a}\right) \leq\ & 2T\left(r,\frac{\Delta_c^{(k)}f}{f-a}\right)-2N\left(r,\frac{f-a}{\Delta_c^{(k)}f}\right)\\ & +2T\left(r,\frac{\Delta_c^{(k)}f}{f-b}\right)-2N\left(r,\frac{f-b}{\Delta_c^{(k)}f}\right)\\ & +T\left(r,\frac{\Delta_c^{(k)}f}{f-c}\right)-N\left(r,\frac{f-c}{\Delta_c^{(k)}f}\right)-V\left(r,\frac{f-c}{f^{(k)}}\right)\\ & +m(r,f)+S(r,f). \end{aligned}$$

Therefore,

$$m\left(r,\frac{1}{f-a}\right) \tag{3.2}$$

$$\leq 2\left(N\left(r,\frac{\Delta_c^{(k)}f}{f-a}\right)-N\left(r,\frac{f-a}{\Delta_c^{(k)}f}\right)\right)+2\left(N\left(r,\frac{\Delta_c^{(k)}f}{f-b}\right)-N\left(r,\frac{f-b}{\Delta_c^{(k)}f}\right)\right)$$
$$+N\left(r,\frac{\Delta_c^{(k)}f}{f-c}\right)-N\left(r,\frac{f-c}{\Delta_c^{(k)}f}\right)+m(r,f)+S(r,f). \tag{3.3}$$

Thus,

$$\begin{aligned} m\left(r,\frac{1}{f-a}\right) \leq\ & 2N\left(r,\Delta_c^{(k)}f\right)+2N\left(r,\frac{1}{f-a}\right)-2N\left(r,f-a\right)-2N\left(r,\frac{1}{\Delta_c^{(k)}f}\right)\\ & +2N\left(r,\Delta_c^{(k)}f\right)+2N\left(r,\frac{1}{f-b}\right)-2N\left(r,f-b\right)-2N\left(r,\frac{1}{\Delta_c^{(k)}f}\right)\\ & +N\left(r,\Delta_c^{(k)}f\right)+N\left(r,\frac{1}{f-c}\right)-N\left(r,f-c\right)-N\left(r,\frac{1}{\Delta_c^{(k)}f}\right)\\ & +m(r,f)+S(r,f). \end{aligned}$$

Therefore

$$\begin{aligned} m\left(r,\frac{1}{f-a}\right) \leq\ & 5N\left(r,\Delta_c^{(k)}f\right)-5N\left(r,f\right)-5N\left(r,\frac{1}{\Delta_c^{(k)}f}\right)\\ & +2N\left(r,\frac{1}{f-a}\right)+2N\left(r,\frac{1}{f-b}\right)+N\left(r,\frac{1}{f-c}\right)\\ & +m(r,f)+S(r,f). \end{aligned} \tag{3.4}$$

Applying the condition $m(r,f)=S(r,f)$, then from (3.4) we have

$$\begin{aligned} m\left(r,\frac{1}{f-a}\right) \leq\ & 5N\left(r,\Delta_c^{(k)}f\right)-5N\left(r,f\right)-5N\left(r,\frac{1}{\Delta_c^{(k)}f}\right)\\ & +2N\left(r,\frac{1}{f-a}\right)+2N\left(r,\frac{1}{f-b}\right)+N\left(r,\frac{1}{f-c}\right)+S(r,f). \end{aligned}$$

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Therefore

$$\varlimsup_{r\to\infty}\frac{m\left(r,\frac{1}{f-a}\right)}{T(r,\Delta_c^{(n)}f)} \leq 5\varlimsup_{r\to\infty}\frac{N\left(r,\Delta_c^{(k)}f\right)}{T(r,\Delta_c^{(n)}f)} - 5\varlimsup_{r\to\infty}\frac{N(r,f)}{T(r,\Delta_c^{(n)}f)}$$
$$-5\varlimsup_{r\to\infty}\frac{N\left(r,\frac{1}{\Delta_c^{(k)}f}\right)}{T(r,\Delta_c^{(n)}f)} + 2\varlimsup_{r\to\infty}\frac{N\left(r,\frac{1}{f-a}\right)}{T(r,\Delta_c^{(n)}f)}$$
$$+2\varlimsup_{r\to\infty}\frac{N\left(r,\frac{1}{f-b}\right)}{T(r,\Delta_c^{(n)}f)} + \varlimsup_{r\to\infty}\frac{N\left(r,\frac{1}{f-c}\right)}{T(r,\Delta_c^{(n)}f)},$$

implies

$$\delta_{R(n)}^{(0)}(a,\Delta_c f)$$
$$\leq 5[1-\Delta_{R(n)}^{(k)}(\infty,\Delta_c^{(k)}f)] + 5[1-\Delta_{R(n)}^{(0)}(\infty,\Delta_c f)] + 5[1-\Delta_{R(n)}^{(k)}(0,\Delta_c^{(k)}f)]$$
$$+2[1-\delta_{R(n)}^{(0)}(a,\Delta_c f)] + 2[1-\delta_{R(n)}^{(0)}(b,\Delta_c f)] + [1-\delta_{R(n)}^{(0)}(c,\Delta_c f)].$$

Hence

$$3\delta_{R(n)}^{(0)}(a,\Delta_c f) + 2\delta_{R(n)}^{(0)}(b,\Delta_c f) + 3\delta_{R(n)}^{(0)}(c,\Delta_c f) + 5\Delta_{R(n)}^{(0)}(\infty,\Delta_c f)$$
$$\leq 5\Delta_{R(n)}^{(k)}(\infty,\Delta_c^{(k)}f) + 5\Delta_{R(n)}^{(k)}(0,\Delta_c^{(k)}f).$$

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Original Article

Uniqueness Of Product of Difference-Differential Polynomials of Entire Functions Sharing a Non-Zero Polynomial of Certain Degree with Finite Weight

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Abstract
In this paper, we establish the results concerning to the product of difference-differential polynomials that share a non-zero polynomial. Thereby extending investigate on uniqueness properties of entire functions when their associated difference polynomials share a non-zero polynomial of a finite degree.
Keywords: *Nevanlinna theory, Meromorphic functions; Entire functions; Uniqueness; Weighted Sharing; Product of difference-differential polynomial, etc.*

1. Introduction and results

In this paper, the term "meromorphic" will always mean meromorphic in the complex plane $\mathbb{C}$. We shall use the standard notation in Nevanlinna's value distribution theory of meromorphic functions (see, e.g.,[7], [9] [14]). A complex function $f(z)$ is said to be analytic at a point z, if it is differentiable at z as well as at all points in a neighborhood of z. A complex function $f(z)$ is analytic in domain D, if it is analytic at each and every point of D. An analytic function, which is analytic in the whole complex plane $\mathbb{C}$ is called an entire function. Meromorphic functions are analytic in $\overline{\mathbb{C}}$ except at isolated poles. Thus entire functions are special case of meromorphic functions. We use notations $\sigma(f)$ and $\lambda(f)$ for the order and the exponent of convergence of zeros of $f(z)$ respectively.
Let k be a positive integer and $a \in \mathbb{C} \cup \{\infty\}$. We denote by $N_{k)}(r, 1/(f-a))$ the counting function of a- points of f with multiplicity $\leq k$, by $N_{(k}(r, 1/(f-a))$ the counting function of a- points of f with multiplicity $\geq k$; and denote the reduced counting function by $\overline{N}_{k)}(r, 1/(f-a))$, $\overline{N}_{(k}(r, 1/(f-a))$, respectively. Set $N_k(r, 1/(f-a)) = \overline{N}(r, 1/(f-a)) + \overline{N}_{(2}(r, 1/(f-a)) + ... + \overline{N}_{(k}(r, 1/(f-a))$.

In 2001, Lahiri first introduced a gradation of sharing of values which we call as weighted sharing, which measures how close a shared value is to being shared IM or to being shared CM.

Definition 1.1. ***(Weighted sharing)***
Let k be a non-negative integer or infinity. For $a \in \overline{\mathbb{C}}$, we denote by $E_k(a, f)$ the set of all a-points of $f(z)$ where an a-point of multiplicity m is counted m times if $m \leq k$ and $k+1$ times if $m > k$. If $E_k(a, f) = E_k(a, g)$, we say that $f(z)$ and $g(z)$ share the value 'a' with weight k.

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The definition implies that if $f(z)$ and $g(z)$ share a value $'a'$ with weight k, then z_0 is an a-point of $f(z)$ with multiplicity $m(\leq k)$ if and only if it is an a-point of $g(z)$ with multiplicity $m(\leq k)$ and z_0 is an a-point of $f(z)$ with multiplicity $m(> k)$ if and only if it is an a-point of $g(z)$ with multiplicity $n(> k)$, where m is not necessarily equal to n.

In the past decades, the related results of difference analogues of meromorphic functions has become a subject of great importance ([1], [2], [5],[6],[9],[12]).

Now we recall some well-known definitions in the difference-differential equations.
In 2007, Laine and Yang [8] proved the following result.

Theorem 1.A. *Let f be a transcendental entire function of finite order and c be a non-zero complex constant. Then for $n \geq 2$, $f^n(z)\, f(z+c)$ assumes every non-zero value $a \in C$ infinitely often.*

In 2010, J.Zhang [15] proved the following analogue results in difference.

Theorem 1.B. *Let $f(z)$ be a transcendental entire function of finite order, and $\alpha(z)$ be a small function with respect to $f(z)$. Suppose that c is a non-zero complex constant and n is an integer. If $n \geq 2$, then $f^n(z)(f(z)-1)f(z+c)-\alpha(z)$ has infinitely many zeros.*

Theorem 1.C. *Let $f(z)$ and $g(z)$ be two transcendental entire functions of finite order, and $\alpha(z)$ be a small function with respect to both $f(z)$ and $g(z)$. Suppose that c is a non-zero complex constant. $n \geq 7$, if $f^n(z)(f(z)-1)f(z+c)$ and $g^n(z)(g(z)-1)g(z+c)$ share $\alpha(z)$ CM, then $f(z) \equiv g(z)$.*

Theorem 1.D. *Let $f(z)$ be a transcendental entire function of finite order, and $\alpha(z)$ be a small function with respect to $f(z)$. Suppose that c is a non-zero complex constant and n is an integer. If $n \geq 2$, $k \geq 1$ then $f^n(z)(f(z)-1)^k f(z+c)-\alpha(z)$ has infinitely many zeros.*

Theorem 1.E. *Let $f(z)$ and $g(z)$ be two transcendental entire functions of finite order, and $\alpha(z)$ be a small function with respect to both $f(z)$ and $g(z)$. Suppose that c is a non-zero complex constant. $k \geq 1$, $n \geq k+6$, if $f^n(z)(f(z)-1)^k f(z+c)$ and $g^n(z)(g(z)-1)^k g(z+c)$ share $\alpha(z)$ CM, then $f(z) \equiv t\, g(z)$, where $t^k = 1$.*

In 2014, X. M. Li, H. X. Yi and W. L. Li proved the following theorem on uniqueness of difference polynomials of meromorphic functions sharing a small function.
Further, K. Y. Zhang and H. X. Yi extended the result of X. M. Li, H. X. Yi and W. L. Li[?] and proved the following theorem on uniqueness of product of differential-difference polynomials of meromorphic functions.

Theorem 1.1. *([12]) If $f(z)$ and $g(z)$ are transcendental entire functions of finite order, $\alpha(z) \not\equiv 0$ be a common small function with respect to $f(z)$ and $g(z)$, $c_j (j = 1, 2, \cdots, d)$ be distinct finite complex numbers and n, m, d and $v_j (j = 1, 2, \cdots, d)$ are non-negative integers. If $n \geq 4k - m + \sigma + 9$ and the differential-difference polynomial $(f^n(z)(f(z)-1)^m \prod_{j=1}^{d} f(z+c_j)^{v_j})^{(k)}$ and $(g^n(z)(g(z)-1)^m \prod_{j=1}^{d} g(z+c_j)^{v_j})^{(k)}$ share $\alpha(z)$ CM, then $f \equiv g$.*

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Recently, R. S. Dyavanal and . M. Hattikal improved the Theorem 1.1 by considering uniqueness problems on product of difference polynomials of meromorphic functions.

Theorem 1.2. *([17]) If $f(z)$ and $g(z)$ are two transcendental meromorphic functions of hyper order satisfying $\rho_2(f) < 1$, $\rho_2(g) < 1$. Let k, n, d, λ be positive integers and $n > max\{2d(k+2) + \lambda(k+3) + 7, \lambda_1, \lambda_2\}$. If $F(z)$ and $G(z)$ share z CM and f, g share $infinity$ IM, then one of the following two conclusions holds.*

(1) $F(z) = G(z)$

(2) $\prod_{j=1}^{d} f(z+c_j))^{(s_j)} = C_1 e^(Cz^2)$, $\prod_{j=1}^{d} g(z+c_j))^{(s_j)} = C_2 e^(- Cz^2)$ *where* C_1, C_2 *and* C *are constants such that* $4(C_1C_2)^{n+1}C^2 = -1$

2. Main Results

In the present paper, we consider the difference polynomials of entire functions of the form $F = f^n(z)(P(f))\prod_{j=1}^{d} f(z+c_j)$ and prove the following theorems.

Theorem 2.1. *Let $f(z), g(z)$ be transcendental entire functions of finite order, $c \neq 0$, and let $p(z)$ be a nonzero polynomial with $\deg(p) \leq n-1$, $n \geq 1$, $m^* \geq 0$ such that $n > m^* + 5$. Let*

$$P(\omega) = a_m\omega^m + \cdots + a_0$$

be nonzero. If $f^n P(f)\prod_{j=1}^{d} f(z+c_j))^{(s_j)} - p$ and $g^n P(g)\prod_{j=1}^{d} g(z+c_j))^{(s_j)} - p$ share $(0, \ell)$, then one of:

(1) $\ell \geq 2,\ m = 0,\ n \geq 2m + d + 5,$
(2) $\ell \geq 2,\ m = \infty,\ n \geq m + d + 4,$
(3) $\ell = 1,\ m = 0,\ n \geq 5m + d + 16,$
(4) $\ell = 0,\ m = 0,\ n \geq 7m + d + 22,$
(5) $f \equiv tg$ *with* $t^{n+1} = 1$.

3. Some preliminary results

To prove our theorems we require the following Lemmas.
Let F and G be two non-constant meromorphic functions defined in $\mathbb{C}$. We also denote by H, the following function

$$H = \left(\frac{F''}{F'} - \frac{2F'}{F-1}\right) - \left(\frac{G''}{G'} - \frac{2G'}{G-1}\right)$$

As mentioned in Section 1, Halburd and Korhonen [5] and Chiang and Feng [2] investigated the value distribution theory of difference expressions. A key result, which is a difference analogue of the logarithmic derivative lemma, read as follows.

Lemma 3.1. [2] *Let $a_n \not\equiv 0, a_{n-1}, \ldots, a_0$ be meromorphic with $T(r, a_i) = S(r, f)$. Then*

$$T(r, a_nf^n + \cdots + a_0) = nT(r, f) + S(r, f).$$

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Lemma 3.2. [2] *Let f be a meromorphic function of finite order and c is a nonzero complex constant. Then*

$$m\left(r, \frac{f(z+c)}{f(z)}\right) + m\left(r, \frac{f(z)}{f(z+c)}\right) = S(r,f)$$

Lemma 3.3. [2] *Let f be a meromorphic function of finite order ρ and c is a non-zero complex constant. Then , for each $\epsilon > 0$, we have*

$$T(r, f(z+c) = T(r,f) + O(r^{\rho-1+\epsilon}) + O(log\ r)$$

From Lemma 2.2, it is evident that $S(r, f(z+c)) = S(r,f)$.

Lemma 3.4. [3] *Let f be a meromorphic function with finite exponent of convergence of poles $\lambda(\frac{1}{f})$ and c is a non-zero complex constant. Then, for each $\epsilon > 0$, we have*

$$N(r, 0, f(z+c)) \leq N(r, 0, f) + S(r,f)$$

$$\overline{N}(r, 0, f(z+c)) \leq \overline{N}(r, 0, f) + S(r,f)$$

$$N(r, f(z+c)) \leq N(r,f) + S(r,f)$$

$$\overline{N}(r, f(z+c)) \leq \overline{N}(r,f) + S(r,f)$$

Lemma 3.5. [17] *Let $f(z)$ be a meromorphic function of finite order ρ and let c be a fixed non-zero complex constant and let $n \in \mathbb{N}$ and $P(w)$ and F are defined as in Theorem 1.1. Then for each $\epsilon > 0$, we have*

$$T(r, F) \leq (n+m+d)T(r,f) + S(r,f)$$

Lemma 3.6. [18] *Let $f(z)$ and $g(z)$ be two non-constant meromorphic functions sharing (1,2). Then one of the following holds:* *i.* $T(r,f) \leq N_2\left(r, \frac{1}{f}\right) + N_2\left(r, \frac{1}{G}\right) + N_2(r,F) + N_2(r,G) + S(r,F) + S(r,G)$

ii. $F \equiv G$;

iii. $FG \equiv 1$.

Where $N_2(r, \frac{1}{F})$ denote the counting function of zeros of F such that simple zeros counted once and multiple zeros counted twice.

Lemma 3.7. [18] *Let $f(z)$ be entire transcendental of finite order σ, $c \neq 0$, $n \geq 1$, $m^* \geq 0$, and $a(z) \not\equiv 0, \infty$ small. If $n > 1$, then $f^n P(f) \prod_{j=1}^{d} f(z+c_j)) - a(z)$ has infinitely many zeros.*

Lemma 3.8 (Hadamard Factorization Theorem). [18] *Let $f(z)$ be entire of finite order ρ with zeros $a_1, a_2, \ldots$ (counting multiplicity). Then f can be written*

$$f(z) = Q(z)e^{\alpha(z)},$$

where $\alpha(z)$ is a polynomial of degree $\leq [\rho]$ and $Q(z)$ is the canonical product formed from zeros.

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Lemma 3.9. [16] *Let $f(z), g(z)$ be entire transcendental of finite order, $c \neq 0$, $p(z)$ a nonzero polynomial,* $\deg(p) \leq n-1$. *Suppose*

$$f^n P(f) \prod_{j=1}^{d} f(z+c_j) \cdot g^n P(g) \prod_{j=1}^{d} g(z+c_j) \equiv p^2.$$

Then $P(\omega) = a_i\omega^i$ is a monomial. If $p(z) = b \neq 0$ constant, then $f = e^{\alpha(z)}$, $g = e^{\beta(z)}$ for polynomials α, β with $\alpha + \beta \equiv d$, and $a_i^2 e^{(n+i+1)d} = b^2$.

Lemma 3.10. [16] *Let $f(z), g(z)$ be entire transcendental of finite order, $c \neq 0$, and $P(\omega)$ as in Theorem 2.1 with at least two nonzero a_i. Then*

$$f^n P(f) f \prod_{j=1}^{d} f(z+c_j) \cdot g^n P(g) \prod_{j=1}^{d} g(z+c_j) \not\equiv p^2.$$

Lemma 3.11. [16] *Let f, g be non-constant meromorphic sharing $(1,1)$ and $H \not\equiv 0$. Then*

$$N(r, 1; F| = 1) = N(r, 1; G| = 1) \leq N(r, H) + S(r, F) + S(r, G).$$

Lemma 3.12. [16] *Let f be transcendental meromorphic of finite order, and $F = f^n P(f) f(z+c)$, $n \in \mathbb{N}$. Then*

$$(n-2)T(r, f) \leq T(r, F) + S(r, f).$$

4. Proof of Main Results

proof Set $F = f^n P(f) \prod_{j=1}^{d} f(z+c_j)$ and $G = g^n P(g) \prod_{j=1}^{d} g(z+c_j)$.
Case 1: $H \not\equiv 0$. By Lemma 3.1 and the Second Fundamental Theorem for F, G,

$$\begin{aligned}(n+m+d)[T(r,f)+T(r,g)] \leq\ & N(r,0;F) + N(r,1;F) + N(r,\infty;F) \\ & + N(r,0;G) + N(r,1;G) + N(r,\infty;G) \\ & - N(r,0;F') - N(r,0;G') + S(r,f) + S(r,g). \quad (4.1)\end{aligned}$$

Now we split into subcases:

(i) $\ell \geq 2$, $m = 0$. Using Lemmas 3.1,3.3,3.11 and (4.1), one obtains

$$(n-2m-d-4)[T(r,f)+T(r,g)] \leq S(r,f) + S(r,g),$$

contradicting $n \geq 2m + d + 5$.

(ii) $\ell \geq 2$, $m = \infty$. Similarly, we get $(n-m-d-3)[T(r,f)+T(r,g)] \leq S(r,f) + S(r,g)$, contradicting $n \geq m + d + 4$.

(iii) $\ell = 1$, $m = 0$. We obtain $(n-5m-d-15)[T(r,f)+T(r,g)] \leq S(r,f)+S(r,g)$, contradicting $n \geq 5m + d + 16$.

(iv) $\ell = 0$, $m = 0$. We obtain $(n-7m-d-21)[T(r,f)+T(r,g)] \leq S(r,f)+S(r,g)$, contradicting $n \geq 7m + d + 22$.

Case 2: $H \equiv 0$. Integrating (**??**) yields

$$\frac{1}{F-1} = \frac{BG + A - B}{G-1},$$

where A, B are constants, $A \neq 0$. Then F, G share $(1, \infty)$. We consider:

(i) If $B \neq -1$, a contradiction is obtained using Lemma 3.12 as in Case 1.

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(ii) If $B = -1$, then $FG \equiv 1$, i.e. $f^n P(f) \prod_{j=1}^{d} f(z+c_j)\, g^n P(g) \prod_{j=1}^{d} g(z+c_j) \equiv p^2$. Lemma 3.10 forbids this under our hypotheses.

(iii) If $B = 0$, then $F = (G-1)/A + 1$, leading to a contradiction via Lemma 3.12 and the same arguments.

Hence the only possibility is $f \equiv tg$ with $t^{n+1} = 1$, proving the theorem.

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Original Article

On maximal rwg-closed sets in topological spaces

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Abstract
In this article, we introduce and investigate two new subclasses of generalized sets in topological spaces, namely minimal rwg-open and maximal rwg-closed sets. These classes arise as refinements of rwg-open and rwg-closed sets respectively. Various structural, separation, and decomposition properties are derived. Finally, we illustrate how maximal rwg-closed sets can model stable diagnostic clusters in medical decision systems.

Keywords: *Ṃinimal open set, Ṃaximal closed set, rwg-open set, rwg-closed set.*

Introduction

Minimal and maximal variants of open and closed sets were originally studied by F. Nakaoka and F. Oda (2001–2003) [1] [2] [3]. Later, generalized closed structures such as rwg-closed and rwg-open sets[4] were introduced in the study of generalized topological behavior. We introduced minimal rwg-open and maximal rwg-closed sets in topological spaces and investigate their properties. Let (Ҳ,) (or simply Ҳ) be topological space.

Definition 1: Let ∅≠Ų⊂Ҳ is called minimal open or min-open [1] (resp. maximal open or max-open[2]) set if every open set contained in Ų is either ∅ or Ų (resp. contains Ų is either Ҳ or equal to Ų)
Definition 2: [3] Let ∅≠ Ḩ ⊂Ҳ is called minimal closed or min-closed (resp. maximal closed or max-closed) set if every closed set contained in F is either ∅ or Ḩ (resp. contains Ḩ is either Ҳ or equal to Ḩ).
Definition 3:[5] Let Ą⊆Ҳ is regular open (resp. regular closed) set if Ą = int(cl(Ą)) (resp. Ą = cl(int(Ą))).
Definition 4: [4] Let Ą⊆Ҳ is called a regular weakly generalized closed set *(briefly, rwg-closed) if* cl(int(Ą)) ⊆Ų whenever Ą⊆Ų and Ų is regular-open.
The compliment of rwg-closed set is called rwg-open.

Minimal rwg-open Sets

Definition 1: Let Ų rwg-open set, ∅≠Ų⊂Ҳ is called minimal rwg-open (briefly, min-rwg-
Remark 2.: The example illustrates their independence of minimal open and min-rwg-open sets.
Example 3: Let Ҳ= $\{a_1,b_1,c_1\}$ be with τ =$\{$Ҳ, ∅,$\{a_1\},\{b_1,c_1\}\}$.

- Minimal open sets:$\{\{a_1\},\{b_1,c_1\}\}$
- rwg-open sets:$\{$Ҳ, ∅ ,$\{a_1\},\{b_1\},\{c_1\}, \{a_1,b_1\},\{b_1,c_1\},\{a_1,c_1\}\}$
- Min-rwg-open sets:$\{\{a_1\},\{b_1\},\{c_1\}\}$

Remark 4: The example illustrates their independence from standard minimal open sets.
open) if every rwg-open set which is contained in Ų is either ∅ or equal to Ų.

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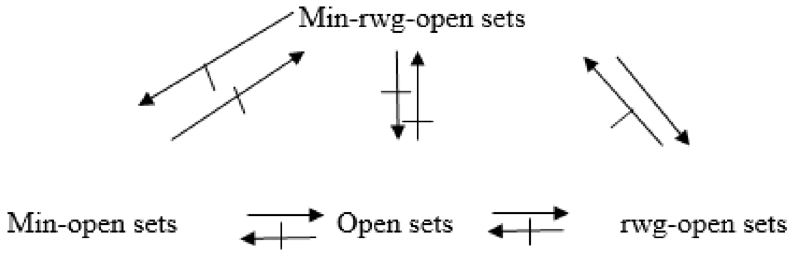

Theorem 5: (i) If Ụ is min-rwg-open and W is rwg-open, then Ụ∩W= ∅ or Ụ⊂W.
(ii) If Ụ and Ỵ are min-rwg-open, then Ụ∩Ỵ= ∅ or Ụ=Ỵ.
Proof: (i) If Ụ∩W= ∅, then Ụ∩W⊆Ụ (rwg-open). Minimality forces Ụ∩W=Ụ , So Ụ⊂W.
(ii) If Ụ∩Ỵ≠ ∅, then Ụ⊆Ỵ and Ỵ⊆Ụ by (i), So Ụ=Ỵ.

Theorem 6: Let Ụ be min-rwg-open and ꭗ∈Ụ. Then Ụ⊆W for any open neighbourhood W of ꭗ.
Proof: If Ụ⊄W, then Ụ∩W is rwg-open, ∅ ≠ Ụ∩W⊂Ụ, contradicting minimality.

Theorem 7: Let Ụ be min-rwg-open and ꭗ ∈Ụ. Then Ụ⊂W for any rwg-open set W containing ꭗ .
Proof: Identical to Theorem 2.6, replacing "open neighborhood" with "rwg-open set."

Theorem 8: Let Ụ be min-rwg-open and ꭗ ∈Ụ. Then Ụ= ∩{W | ꭗ∈W rwg-open}
Proof: Theorems 2.7 and ꭗ∈Ụ give Ụ⊆∩{W}⊆Ụ.

Theorem 9: For non-empty rwg-open Ụ, these are equivalent:
(i) Ụ min-rwg-open
(ii) Ụ⊂ rwg-cl(S) for every non-empty S ⊆ Ụ
(iii) rwg-cl(Ụ)= rwg-cl(S) for every non-empty S ⊆ Ụ

Proof:
(i)⇒(ii): For ꭗ∈Ụ, Theorem 2.7 gives Ụ⊆W (rwg-open containing ꭗ), so S⊆W and ꭗ∈rwg-cl(S)
(ii)⇒(iii): S⊆Ụ gives rwg-cl(S)⊆rwg-cl(Ụ); (ii) gives reverse inclusion..
(iii) ⇒ (i): If not minimal, ∃ rwg-open Ỵ⊊Ụ, Ỵ≠∅. Pick a∈Ụ\Ỵ.
Then rwg-cl({a})⊆X\Ỵ⊊ rwg-cl(Ụ), contradicting (iii).

Corollary 2.9.1 (Dense-in-itself) Min-rwg-open Ụ satisfies Ụ⊆rwg-cl(Ụ\{ꭗ}) ∀ ꭗ∈Ụ

Theorem 10: Every non-empty finite rwg-open set Ỵ contains a (finite) min-rwg-open set Ụ⊂Ỵ.
Proof: If Ỵ minimal, done. Else construct strictly decreasing chain $Ỵ⊋Ỵ_1⊋Ỵ_2⊋…$of non-empty rwg-open sets. Finiteness forces termination at minimal $Ụ=Ỵ_n$.
Corollary 2.10.1: In a locally finite space, every non-empty rwg-open Ỵ contains a min-rwg-open Ụ⊆Ỵ.
Proof: Pick ꭗ∈Ỵ. Finite open $Ỵ_ꭗ∋ꭗ$ gives finite rwg-open $Ỵ∩Ỵ_ꭗ$; apply Theorem 2.10.
Corollary 2.10.2: Every finite minimal open set contains a min-rwg-open set.
Proof: Finite minimal open sets are finite rwg-open; apply Theorem 2.10

Theorem 11: If min-rwg-open $Ụ⊂\bigcup_{\lambda\epsilon\Lambda} Ụ_\lambda$ ($Ụ_\lambda$ minimal rwg-open), then $Ụ=Ụ_\lambda$ for some λ.
Proof: $Ụ∩\bigcup_{\lambda\epsilon\Lambda} Ụ_\lambda = Ụ \neq \emptyset$, so some $Ụ∩Ụ_\lambda= Ụ$ (Theorem 2.5(ii)), hence $Ụ= Ụ_\lambda$.

Theorem 12: Distinct min-rwg-open sets $Ụ \neq Ụ_\lambda$ (λ∈Λ) satisfy $Ụ∩\bigcup_{\lambda\epsilon\Lambda} Ụ_\lambda= \emptyset$
Proof: If non-empty, some $Ụ∩Ụ_\lambda\neq\emptyset$ gives $Ụ=Ụ_\lambda$ (Theorem 2.5(ii)), contradiction.

Theorem 13: For distinct min-rwg-open $\{Ụ_\lambda\}_{\lambda\in\Lambda}$ (|Λ| ≥2) , any $\bigcap_{\mu\neq\mu0}Ụ_\mu=\emptyset$.
Proof: Apply Theorem 2.12 with $Ụ= U_{\mu0}$.
Corollary 2.13.1: Distinct min-rwg-open $\{Ụ_\lambda\}_{\lambda\in\Lambda}$ have empty intersection over any proper non-empty subset of Λ.

Theorem 14: If min-rwg-open $Ụ_\lambda$ (λ∈Λ) and $Ụ_\gamma$ (γ ∈ Γ) satisfy $Ụ_\lambda\neq Ụ_\gamma$ for all λ,γ, then
$\bigcup_{\lambda\epsilon\Lambda} Ụ_\lambda \not\subset \bigcup_{\gamma\epsilon\Gamma} Ụ_\gamma$
Proof: If contained, Theorem 2.11 gives some $Ụ_\lambda=Ụ_\gamma$, contradiction.

Theorem 15 (Separation property) Distinct min-rwg-open sets Ụ≠Ỵ satisfy rwg-int(Ụ∪Ỵ)=Ụ∪Ỵ.

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Proof: If not, some rwg-closed points separate them, contradicting Theorem 2.7.

Maximal rwg-closed Sets

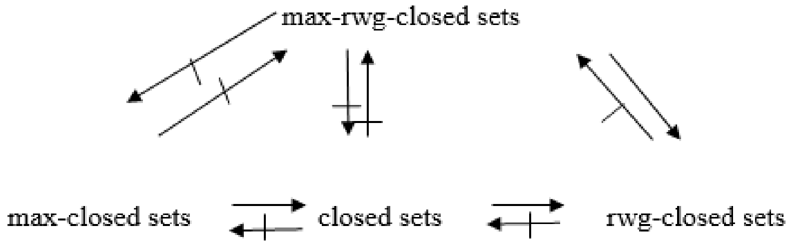
Definition 3.1: Let H rwg-closed, $\emptyset \neq H \subset X$ is called Maximal rwg-closed (briefly, max-rwg-closed) set if every rwg-closed set which containing H is either H itself or the entire space X.

Remark 3.2: Max-closed and Max-rwg-closed sets are independent concepts, illustrates from the example.

Example 3.3: Consider $X=\{a_1,b_1,c_1\}$ with topology $\tau=\{X, \emptyset, \{a_1\}, \{b_1,c_1\}\}$.

- closed sets: $\{X, \emptyset, \{a_1\}, \{b_1,c_1\}\}$
- maximal closed: $\{\{a_1\}, \{b_1,c_1\}\}$
- rwg-closed sets: $\{X, \emptyset, \{a_1\}, \{b_1\}, \{c_1\}, \{a_1,b_1\}, \{b_1,c_1\}, \{a_1,c_1\}\}$
- max-rwg-closed sets: $\{\{a_1,b_1\}, \{b_1,c_1\}, \{a_1,c_1\}\}$

Remark 3.4: The example illustrates their independence from standard maximal closed sets



Theorem 3.5: A subset $\emptyset \neq H \subset X$ is a max-rwg-closed if and only if X-H is a min-rwg-open set.

Proof: Suppose H is Max-rwg-closed but X-H is not a min-rwg-open. Then there exists rwg-open $U \neq X-H$ with $\emptyset \neq U \subset X$-$H$, so $H \subset X$-U, where X-U is rwg-closed. This contradicts the maximality of H. Thus, X-H is min-rwg-open. Conversely, suppose X-H is minimal rwg-open, but H is not a Maximal rwg-closed. Then there exists rwg- closed set $E \neq H$ with $H \subset E \neq X$, so $\emptyset \neq X$-$E \subset X$-H, where X-E is rwg-open set. This contradicts the minimality of H. Thus, H is max-rwg-closed.

Theorem 3.6: (i) If H is max-rwg-closed and W is rwg-closed, then either $H \cup W = X$ or $W \subset H$.
(i) If H and S are max-rwg-closed, then either $H \cup S = X$ or $H = S$

Proof: (i) If $H \cup W = X$, done. Otherwise, $H \subset H \cup W$ and $H \cup W$ is rwg-closed (finite union of rwg-closed sets). By maximality of H, either $H \cup W = X$ (contradiction) or $H \cup W = H$, so $W \subset H$.
(ii) If $H \cup S \neq X$, then $H \subset S$ and $S \subset H$ by (i), so $H = S$.

Corollary 3.6.1 (Prime-like property): max-rwg-closed sets behave like prime ideals: if H is max-rwg-closed and $A \cup B = X$ with A, B rwg-closed, then $A \subset H$ or $B \subset H$.

Proof: Suppose neither holds.
Then $H \cup A \neq X$ and $H \cup B \neq X$, so $A \subset H$ and $B \subset H$ by Theorem 3.6(i), contradicting $A \cup B = X$.

Corollary 3.6.2: The intersection of any collection of max-rwg-closed sets is either empty or contained in one of them.

Proof: Let $\{H_i\}$ be max-rwg-closed sets and $I = \cap H_i \neq \emptyset$. Pick $x \in I$. By Theorem 3.7, for any H_j, either $H_j \cup H_k = X$ (so $I \subseteq H_k^c \not\subset H_j$) or $H_k \subseteq H_j$.
Thus some H_j contains all others intersecting I.

Theorem 7: Let H be max-rwg-closed. If $x \in H$, then for any rwg-closed set S containing x, either $H \cup S = X$ or $S \subset H$

Proof: Similar to Theorem 3.6.

Theorem 8: Let $H_\alpha, H_\beta, H_\gamma$ be max-rwg-closed sets with $H_\alpha \neq H_\beta$. If $H_\alpha \cap H_\beta \subset H_\gamma$, then either $H_\alpha = H_\gamma$ or $H_\beta = H_\gamma$.

Proof: Assume that $H_\alpha \neq H_\gamma$, we show $H_\beta = H_\gamma$:

$H_\beta \cap H_\gamma = H_\beta \cap (H_\gamma \cap X) = H_\beta \cap (H_\gamma \cap (H_\alpha \cup H_\beta)$ (By Theorem 3.6 (ii))
$= H_\beta \cap ((H_\gamma \cap H_\alpha) \cup (H_\gamma \cap H_\beta))$
$= (H_\beta \cap H_\gamma \cap H_\alpha) \cup (H_\beta \cap H_\gamma) = (H_\alpha \cap H_\beta) \cup (H_\gamma \cap H_\beta)$ (idempotence)
$= (H_\alpha \cup H_\gamma) \cap H_\beta = X \cap H_\beta$ (By Theorem 3.6 (ii))
$= H_\beta$

So $H_\beta \cap H_\gamma = H_\beta$. Since both are maximal rwg-closed, $H_\beta = H_\gamma$.

Corollary 3.8.1: No max-rwg-closed set properly contains the intersection of two distinct max-rwg-closed sets.

Proof: If $H\alpha \cap H\beta \subset H\gamma$ with all distinct, Theorem 3.8 forces equality, contradiction.

Theorem 9: Let $H_\alpha, H_\beta, H_\gamma$ be distinct max-rwg-closed sets. Then $(H_\alpha \cap H_\beta) \not\subset (H_\alpha \cap H_\gamma)$.

Proof: Suppose $H_\alpha \cap H_\beta \subset H_\alpha \cap H_\gamma$. Then $(H_\alpha \cap H_\beta) \cup (H\gamma \cap H_\beta) \subset (H_\alpha \cap H_\gamma) \cup (H\gamma \cap H_\beta)$,

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So $(H_\alpha \cup H_\gamma) \cap H_\beta \subset H_\gamma \cap (H_\alpha \cup H_\beta)$. By Theorem 3.6 (ii) $H_\alpha \cap H_\gamma = X$ and $H_\alpha \cap H_\beta = X$, yielding $H_\beta \subset H_\gamma$. Maximality forces $H_\beta = H_\gamma$. Contradicting distinctness.
Therefore $(H_\alpha \cap H_\beta) \not\subset (H_\alpha \cap H_\gamma)$.

Theorem 10: Let H be max-rwg-closed and $x \in H$. Then $H = \cup\{S : S \text{ rwg-closed}, x \in S, H \cup S \neq X\}$.
Proof: By Theorem 3.7, $H = \cup\{S: S \text{ rwg-closed}, x \in S, H \cup S \neq X\} \subset H$.

Theorem 11: Every Proper non-empty co-finite rwg-closed subset H is contained in a cofinite max-rwg-closed set E.
Proof: If H is maximal, set $E = H$. Otherwise, construct $H \subset H_1 \subset H_2 \ldots$ of cofinite rwg-closed sets, each properly containing the previous and not equal to X. Co-finiteness ensures the chain terminates at maximal $E = H_n$ for some positive integer n.

Theorem 12: Let H be maximal rwg-closed. If $x \in X - H$. For any rwg-closed E containing x, $X - H \subset E$.
Proof: By Theorem 3.6(ii), $E \cup H = X$, so $X - H \subset E$.

Theorem 13 (Irreducible decomposition): Every proper rwg-closed set $E \neq \emptyset$ can be expressed as intersection of max-rwg-closed sets containing it.
Proof: By Theorem 3.11(cofinite case) or direct chain construction, extend E to maximal $H_1 \supseteq E$. If $E \neq H_1$, find $H_2 \supseteq E$ with $H_1 \not\subset H_2$. Continue; distinct maximal sets have empty intersection with complements, so intersection stabilizes at E

Maximal rwg-Closed Sets in Medical Diagnosis:
Concrete Examples

Max-rwg-closed sets identify maximal patient clusters with consistent symptom profiles, serving as decision boundaries in diagnosis.

Example 4.1: COVID-19 Diagnosis (6-Symptom Space)
Patient space $X = \{p_1, p_2, p_3, p_4, p_5, p_6\}$ with symptoms: Fever(F), Cough(C), Fatigue(T), O2-low(L), Age>60(A), Loss of Taste(S)
Topology induced by test results: $\tau = \{X, \emptyset, \{F,C\}, \{L,A\}, \{F,C,L,A\}\}$ or
$\tau = \{X, \emptyset, \{p_1, p_2\}, \{p_4, p_5\}, \{p_1, p_2, p_4, p_5\}\}$
rwg-closed sets: X, $\emptyset$, {p1,p2,p3}, {p4,p5,p6}, {p1,p2}, {p3,p4}, {p1,p6} singletons
Maximal rwg-closed: {p1,p2,p3}, {p4,p5,p6}
F1 = {p1,p2,p3} = "Fever+Cough+Fatigue" → COVID POSITIVE cluster
F2 = {p4,p5,p6} = "O2-low+Age>60+No Taste" → COVID POSITIVE cluster
F1 ∪ F2 = X (p6 uncertain), F1 ∩ F2 = ∅ (Thm 3.6(ii))
Diagnosis: Patients in F1 or F2 → High Risk. Boundary, patient p6 needs further testing.

Example 4.2: Breast Cancer Diagnosis (TNM Staging)
X={T1,N0,M0},{T1,N1,M0},{T2,N0,M0},{T2,N1,M0},{T3,N0,M0}
Max-rwg-closed sets:
F1 = {T1N0M0, T1N1M0, T2N0M0} = "Early-Intermediate Stage"
F2 = {T2N1M0, T3N0M0} = "Locally Advanced Stage"
Property (Theorem 3.9): F1 ∩ F2 = {T2N1M0} ⊈ F1, ⊈ F2

Clinical Decision:
F1 → Surgery + Radiation (5-yr survival >85%)
F2 → Neoadjuvant Chemo + Surgery (5-yr survival ~65%)
Boundary T2N1M0 → Multidisciplinary review

Example 4.3: Diabetes Classification (3-Patient Cohort)
Patients: p1 (High-Glucose, BMI>30), p2 (High-Glucose, Normal-BMI), p3 (Normal-Glucose, BMI>30)
space $X = \{p_1, p_2, p_3\}$ with topology $\tau = \{X, \emptyset, \{p_1,p_2\}, \{p_1,p_3\}\}$
rwg-closed: X, $\emptyset$, $\{p_1\}$, $\{p_2\}$, $\{p_3\}$, $\{p_1,p_2\}$, $\{p_1,p_3\}$, $\{p_2,p_3\}$
Maximal rwg-closed: $\{p_1,p_2\}$, $\{p_1,p_3\}$
By Theorem 3.8: $\{p_1,p_2\} \cap \{p_1,p_3\} = \{p_1\} \not\subseteq$ any other maximal

Diagnosis Mapping:
{p1,p2} = "High Glucose ± Obesity" → Type 2 Diabetes
{p1,p3} = "Obesity ± High Glucose" → Prediabetes/Metabolic Syndrome
p_1 = boundary patient (needs OGTT confirmation)

Example 4.: Heart Disease Risk (4-Symptom Profile)

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Ӽ = {p1, p2, p3, p4} Symptoms: HTN, Chol, Smoke, FamHx
τ = {Ӽ, ∅, {HTN, Chol}, {Smoke, FamHx}}
Maximal rwg-closed:
F1 = {HTN+Chol+Smoke} = "Classical Risk Triad"
F2 = {Chol+Smoke+famHx} = "Familial Hypercholesterolemia"
F1 ∪ F2 = Ӽ (By Theorem 3.6(ii)) → Complete risk stratification

Decision Table: Max-rwg-closed → Treatment Protocol

Max-rwg-closed set	Patient profile	Treatment protocol
COVID F1	Fever+Cough+Fatigue	Hospital Admit + Remdesivir
COVID F2	O2-low+Age>60	ICU + Ventilation
Cancer F1	T1-T2, N0-N1	Surgery + Radiation
Cancer F2	T2-T3, N1	Neoadjuvant Chemo
Diabetes F1	High Glu ± Obesity	Metformin + Lifestyle
Heart F1	HTN+Chol+Smoke	Statin +BP Med + Cessation

Key Clinical Advantages:
1. Theorem 3.6:F∪W=Ӽ or W⊆F→ Complete stratification (no patient left unclassified)
2. Theorem 3.11: Cofinite data → Guaranteed maximal sets exist
3. Corollary 3.6.1: Prime-like → Clean decision boundaries
4. Theorem 3.10: Pointwise decomposition → Patient-specific risk

Primary Medical Value: Max-rwg-closed sets automatically generate evidence-based treatment clusters from symptom topologies, with rigorous guarantees of completeness and boundary separation.

Conclusion:

The systematic study of min-rwg-open sets and max-rwg-closed sets reveals a rich duality (Theorem 3.5) bridging generalized topology with algebraic structure:
Min-rwg-open: Intersection-prime (Theorem 2.5) → "atomic" building blocks
Max-rwg-closed: Union-prime (Theorem 3.6) → "co-atomic" separators

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Original Article

The Role of Computer Technology in Business Development: An Implementation of Modernity for Business Growth

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Abstract

The Role of Computer Technology in Business Development: In this modern era, computer technology serves as the backbone in developing business, implementing technology-based machinery in various types of businesses has helped in developing business at a higher level. Moreover, as the population and demand increase, technology is essential to improve operational efficiency to foster innovation and ensure competitive advantage in the fast-paced market. This implementation is shifting from manual, local processes to automated, globalized and data-driven systems. It is better to implement modern technology such as cloud computing, artificial intelligence (AI) and advanced analytics for business improvements.

This study examines highlighting how digital tools and information systems serve as critical drivers of organizational efficiency, innovation, and competitive advantage. The integration of computer technology into business processes—ranging from data management and communication systems to automation and digital marketing—has redefined traditional operational models and enabled firms to adapt to dynamic market environments. The business management includes technological components such as enterprise resource planning systems, cloud computing, e-commerce platforms, artificial intelligence, and data analytics, analyzing their contributions to productivity enhancement, cost reduction, improved customer engagement, and informed decision-making. By implementing modern technological infrastructures, businesses are able to streamline workflows, enhance collaboration, optimize supply chains, and expand into global markets.

It also addresses challenges associated with technology adoption, such as cybersecurity risks, high implementation costs, resistance to change, and the need for continuous skill development. Through qualitative and quantitative analysis, the research demonstrates that organizations that effectively integrate computer technology into their core operations experience accelerated growth, improved performance metrics, and stronger market positioning.

The findings conclude that computer technology is not merely a supportive tool but a fundamental catalyst for modern business development. Its strategic implementation represents a practical embodiment of modernity, enabling businesses to achieve scalability, resilience, and long-term sustainability in an increasingly digital economy.

Keywords: *Technology, Business Development, Modernization, Operational Efficiency, Artificial Intelligence, E-commerce Platforms, Data Protection, Learning, Education.*

Introduction

The implementation of computer technology has emerged as a fundamental of growth, innovation, and competitive advantage, even from small enterprises to multinational corporations, organizations increasingly rely on computer technology to enhance productivity, improve decision-making, and expand market reach. Computer technology encompasses hardware, software, networking systems, data management tools, and digital communication platforms that facilitate the efficient processing and dissemination of information. In today's digital age, businesses utilize technologies such as cloud computing, artificial intelligence, e-commerce platforms, enterprise resource planning systems, and data analytics to streamline operations and deliver value to customers.

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These tools enable organizations to automate routine tasks, reduce operational costs, minimize human error, and optimize resource utilization. The adoption of modern computer technologies supports effective communication and collaboration both internally and externally. Digital platforms allow real-time interaction among employees, clients, suppliers, and stakeholders across geographical boundaries. This connectivity enhances coordination, accelerates decision-making processes, and strengthens customer relationships, all of which are critical components of business development. However, thus its implementation represents a practical expression of modernity that empowers businesses to grow, compete, and thrive in an increasingly dynamic and technology-driven world.

How Business development originate: The origins of business lie in the early stages of human civilization, when people began to produce more goods than they needed for personal survival. Trade emerged as a natural response to the need for exchange, cooperation, and economic organization. For example,

1. Barter system: In ancient times, people directly exchanged goods and services with each other instead of money.

2. Introduction of Money: The invention of money made trade easier and more efficient. Early forms of money included shells, livestock, and metal coins. The kingdom of Lydia (modern-day Turkey) is often credited with producing some of the first metal coins around 600 BCE. Money allowed businesses to grow beyond simple exchange and encouraged saving, investment, and expansion.

3. Growth of Markets and Trade Routes: As societies expanded, trade routes developed. As business flourishes Merchants began specializing in buying and selling goods across regions. Markets became central places where goods were exchanged, marking the early formation of organized business activity.

4. Industrial Revolution: A major transformation occurred during the Industrial Revolution. Machines replaced manual labor, factories were established, and mass production became possible. This period gave rise to modern corporations, banking systems, and international trade on a large scale.

5. Modern Business Era: In the 20th and 21st centuries, business evolved further with globalization and technological advancements. The rise of multinational corporations, digital commerce, and computer technology transformed how businesses operate today.

The technology in business:

Technology plays a vital role in modern business. It improves efficiency, enhances communication, supports decision-making, and creates new opportunities for growth. Technology is essential for business success in the modern world. It improves productivity, reduces costs, enhances customer experience, and helps companies stay competitive.

The Role of Computer Technology in Business Growth

Computer technology plays a very important role in the growth and success of modern businesses. From small startups to large multinational companies, computers help organizations work faster, smarter, and more efficiently.

1. **Improved Communication**: Computer technology enables fast and easy communication through emails, video conferencing, and messaging apps. Platforms like Microsoft Teams and Zoom allow businesses to connect with employees, clients, and partners worldwide. This improves teamwork and decision-making.
2. **Increased Productivity**: Computers automate routine tasks such as data entry, billing, payroll, and inventory management. Software like Microsoft Excel helps in calculations and data analysis, saving time and reducing human errors. Automation allows employees to focus on more important and creative tasks.
3. **Better Data Management:** Businesses generate large amounts of data every day. Computer technology helps store, organize, and analyze this data efficiently. Database systems and cloud platforms like Google Drive make it easy to access information anytime and anywhere. Proper data management helps in better decision-making and planning.
4. **Online Marketing and Global Reach:** The internet allows businesses to promote products and services worldwide. Through websites and social media platforms like Facebook and Instagram, companies can reach a global audience. Digital marketing helps businesses grow faster and build strong brand awareness.
5. **E-Commerce and Online Services:** Computer technology has made online shopping possible. Companies use platforms like Amazon and Flipkart to sell products online. This increases sales opportunities and customer convenience.
6. **Financial Management:** Computers help in managing financial records, budgeting, and accounting. Accounting software ensures accurate financial reporting and reduces the risk of mistakes. It also helps businesses track profits and expenses efficiently.
7. **Innovation and Competitive Advantage:** Advanced technologies like Artificial Intelligence (AI), data analytics, and cloud computing help businesses innovate and stay ahead of competitors. Companies that adopt modern computer technologies grow faster and adapt better to market changes.

Discussion:

Computer technology has become the backbone of modern business development. In today's competitive global economy, organizations rely heavily on digital systems to enhance efficiency, improve decision-making, and

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create innovative growth strategies. The integration of computer technology represents the practical implementation of modernity in business operations, transforming traditional methods into dynamic, data-driven systems.

Tools for Computer Technology in Business Development:

Essential computer technology tools for business development include CRM systems for lead management, project management platforms for team alignment, and analytics tools for data-driven insights. Additionally, cloud computing, automation software, and communication tools enhance operational efficiency.

Key Categories and Tools for Business Development:

- **Customer Relationship Management (CRM) & Sales:** HubSpot, Salesforce, Pardot (marketing automation), and Mailchimp for email marketing help attract and manage leads.
- **Project Management & Collaboration:** Trello, Asana, and Slack streamline team tasks, tracking, and instant communication.
- **Data Analytics & Business Intelligence (BI):** Google Analytics, SAP, Oracle BI, and MicroStrategy help analyze market trends and internal performance.
- **Cloud Computing & File Management:** Google Drive and Dropbox ensure secure, shared access to documents.
- **Automation & Workflow Tools:** Zapier connects various apps to automate routine tasks, reducing manual administrative work.
- **Content Management & Marketing:** HubSpot enables content strategy development and lead generation.

Challenges in Computer Technology Adoption in Business Development:

Challenges in adopting computer technology for business development include high financial investment, resistance to cultural change, a shortage of skilled personnel, and integration issues with legacy systems. Overcoming these requires addressing data silos, ensuring cybersecurity, and strategic planning for, to improve operational efficiency and competitiveness. Key challenges to technology adoption in business development include:

Cultural Resistance and Change Management: Employees often resist new technologies due to fear of disruption,, loss of job security, or the effort required to learn new systems.

Financial Constraints: High costs for purchasing, implementing, and maintaining new tools, along with training expenses, act as a primary barrier.

Legacy Systems and Integration Issues: Existing, outdated infrastructure is difficult to integrate with modern, cloud-based, or AI-driven technologies.

Skills Shortage: A lack of internal technical expertise often hinders the ability to manage or fully leverage new, complex digital systems.

Security and Data Privacy: Increased cybersecurity risks and complex, evolving regulatory compliance requirements pose significant hurdles.

Unclear Strategy and ROI: Difficulty in defining a clear digital transformation roadmap and measuring the return on investment can stall projects.

Recommendation for Computer Technology Adoption in Business Development:

Adopting computer technology for business development requires a strategic, phased approach that moves beyond simple digitization to active "techceleration"—anticipating and leveraging rapid technological advancements. Successful adoption transforms IT from a support function into a driver of competitive advantage by focusing on cloud computing, artificial intelligence, and data analytics to increase productivity and operational efficiency.

Conclusion:

The adoption of computer technology is no longer an optional upgrade but a fundamental requirement for modern business development, survival, and sustainable growth. It serves as a crucial driver for increasing operational efficiency, enhancing productivity, fostering innovation, and strengthening competitive advantage.

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Original Article

ಆರ್ಟಿಫಿಶಿಯಲ್ ಇಂಟೆಲಿಜೆನ್ಸ್ ಮತ್ತು ಮಾನವಕುಲ: ಸಾಧ್ಯತೆಗಳು, ಸವಾಲುಗಳು ಮತ್ತು ಭವಿಷ್ಯದ ಮಾರ್ಗ

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ಪೀಠಿಕೆ

ಆರ್ಟಿಫಿಶಿಯಲ್ ಇಂಟೆಲಿಜೆನ್ಸ್ (AI) ಇಂದು ನಮ್ಮ ಜೀವನದ ಅತ್ಯಂತ ಪ್ರಮುಖ ಮತ್ತು ಬದಲಾವಣೆ ತರುವ ತಂತ್ರಜ್ಞಾನವಾಗಿ ಮಾರ್ಪಡಿಸಿಕೊಂಡಿದೆ. ನಮ್ಮ ದೈನಂದಿನ ಜೀವನದಲ್ಲಿ ಬಳಸುವ ಮೊಬೈಲ್ ಫೋನ್, ಕಂಪ್ಯೂಟರ್, ಸ್ಮಾರ್ಟ್ ಸಾಧನಗಳು ಮತ್ತು ಇತರ ಎಲ್ಲಾ ಉಪಕರಣಗಳಲ್ಲಿ AI ಸಂಪೂರ್ಣವಾಗಿ ಸಮ್ಮಿಲಿತಗೊಂಡಿದೆ. ನಾವು ಇಂಟರ್ನೆಟ್‌ನಲ್ಲಿ ಹುಡುಕುವ ಮಾಹಿತಿಯನ್ನು ತಕ್ಷಣ ನೀಡುವುದು, Siri ಅಥವಾ Google Assistan ಅಂತಹ ವಾಯ್ಸ್ ಅಸಿಸ್ಟೆಂಟ್ ಗಳ ಮೂಲಕ ಸಹಜವಾಗಿ ಮಾತನಾಡುವುದು, ಚಿತ್ರಗಳನ್ನು ಗುರುತಿಸಿ ವಿವರಿಸುವುದು, ಚಲನಚಿತ್ರಗಳು ಅಥವಾ ಹಾಡುಗಳನ್ನು ಶಿಫಾರಸು ಮಾಡುವುದು – ಇವೆಲ್ಲವೂ AI ಯ ಅದ್ಭುತ ಕಾರ್ಯಗಳು. ಆದರೆ ಇದು ಕೇವಲ ಸೌಲಭ್ಯವಲ್ಲ; ಇದು ಮಾನವ ಸಮಾಜದ ರೂಪುರೇಖೆ ಬದಲಾವಣೆಗೆ ಕಾರಣವಾಗುತ್ತಿದೆ. ಈ ಸೆಮಿನಾರ್ ಪತ್ರಿಕೆಯಲ್ಲಿ AI ಯ ದೈನಂದಿನ ಉಪಯೋಗಗಳು, ಉದ್ಯಮಗಳಲ್ಲಿನ ಪಾತ್ರ, ಅಪಾಯಗಳು, ತಜ್ಞರ ಎಚ್ಚರಿಕೆಗಳು, ಭವಿಷ್ಯದ ಸಾಧ್ಯತೆಗಳು ಮತ್ತು ನೈತಿಕ ಬಳಕೆಯ ಮಾರ್ಗಸೂಚಿಗಳನ್ನು ವಿವರವಾಗಿ ಚರ್ಚಿಸುತ್ತೇವೆ. AI ಮಾನವಕುಲಕ್ಕೆ ಒಂದು ದ್ವಂದ್ವದ ಆಯುಧವಾಗಿದೆ – ಒಂದೆಡೆ ಅದು ಶಕ್ತಿ ನೀಡುತ್ತದೆ, ಇನ್ನೊಂದೆಡೆ ಅಪಾಯಗಳನ್ನು ಹೊಂದಿದೆ.

AI ಯ ದೈನಂದಿನ ಜೀವನದಲ್ಲಿನ ಆಳವಾದ ಸಂನಾದ

AI ನಮ್ಮ ಜೀವನದಲ್ಲಿ ಈಗಾಗಲೇ ಆಳವಾಗಿ ಸೇರಿಹೊಂದಿದ್ದು, ನಾವು ಗಮನಿಸದೆಯೇ ಅದನ್ನು ಬಳಸುತ್ತಿದ್ದೇವೆ. ಉದಾಹರಣೆಗೆ, Google ಅಥವಾ Bing ಸರ್ಚ್ ಇಂಜಿನ್‌ಗಳು ನಮ್ಮ ಪ್ರಶ್ನೆಗಳನ್ನು ಅರ್ಥಮಾಡಿಕೊಂಡು, ಸಂಬಂಧಿತ ಮಾಹಿತಿಯನ್ನು ಸೂಕ್ಷ್ಮತೆಯಿಂದ ಆಯ್ಕೆಮಾಡಿ ನೀಡುತ್ತವೆ. ಇದು ನ್ಯಾಚುರಲ್ ಲ್ಯಾಂಗ್ವೇಜ್ ಪ್ರಾಸೆಸಿಂಗ್ (NLP) ತಂತ್ರಜ್ಞಾನದಿಂದ ಸಾಧ್ಯವಾಗುತ್ತದೆ. ವಾಯ್ಸ್ ಅಸಿಸ್ಟೆಂಟ್‌ಗಳು – Alexa, Google Home ಅಥವಾ Apple ನ Siri – ನಮ್ಮ ಆದೇಶಗಳನ್ನು ಆಲಿಸಿ, ಲೈಟ್ ಆನ್ ಮಾಡುವುದರಿಂದ ಹಿಡಿದು, ಹವಾಮಾನ ಮಾಹಿತಿ ಹೇಳುವವರೆಗೆ ಎಲ್ಲವನ್ನೂ ನಿರ್ವಹಿಸುತ್ತವೆ. ಇಮೇಜ್ ರೆಕಗ್ನಿಷನ್ ತಂತ್ರದಿಂದಾಗಿ, Facebook ನ Face ID ಅಥವಾ Google Photos ನಲ್ಲಿ ಚಿತ್ರಗಳು ಸ್ವಯಂಚಾಲಿತವಾಗಿ ವರ್ಗೀಕರಿಸಲ್ಪಡುತ್ತವೆ. ಸ್ಟ್ರೀಮಿಂಗ್ ಪ್ಲಾಟ್‌ಫಾರ್ಮ್‌ಗಳಾದ Netflix ಮತ್ತು YouTube ನಲ್ಲಿ AI ಆಧಾರಿತ ಶಿಫಾರಸು ವ್ಯವಸ್ಥೆಗಳು (Recommendation Systems) ನಮ್ಮ ವೀಕ್ಷಣಾ ಇತಿಹಾಸವನ್ನು ವಿಶ್ಲೇಷಿಸಿ, ನಿಖರವಾದ ಸೂಚನೆಗಳನ್ನು ನೀಡುತ್ತವೆ. ಇದರಿಂದ ಸಮಯ ಉಳಿತಾಯವಾಗುತ್ತದೆ ಮತ್ತು ವೈಯಕ್ತಿಕ ಅನುಭವ ಸುಧಾರಿಸುತ್ತದೆ. ಇಂಟರ್ನೆಟ್ ಆಫ್ ಥಿಂಗ್ಸ್ (IoT) ಸಾಧನಗಳಲ್ಲಿ AI ಸ್ಮಾರ್ಟ್ ರೆಫ್ರಿಜರೇಟರ್ ಅಥವಾ ಥರ್ಮೋಸ್ಟ್ಯಾಟ್‌ಗಳಂತಹ ಸಾಧನಗಳನ್ನು ನಿರ್ವಹಿಸುತ್ತದೆ, ಆದರೆ ಇದು ನಮ್ಮ ಜೀವನವನ್ನು ಸುಲಭಗೊಳಿಸುವುದರ ಜೊತೆಗೆ ಡೇಟಾ ಗೌಪ್ಯತೆಯ ಸವಾಲುಗಳನ್ನು ಎದುರಿಸುತ್ತದೆ. ಸಂಕ್ಷಿಪ್ತವಾಗಿ ಹೇಳುವುದಾದರೆ, AI ಇಂದು ನಮ್ಮ ಜೀವನದ ಅವಿಭಾಜ್ಯ ಅಂಗವಾಗಿದೆ.

ಉದ್ಯಮಗಳು ಮತ್ತು ಕ್ಷೇತ್ರಗಳಲ್ಲಿ AI ಪಾತ್ರ .

ಇಂದಿನ ಕಾಲದಲ್ಲಿ ಕಂಪನಿಗಳು ಮತ್ತು ಉದ್ಯಮಗಳು AI ಅನ್ನು ತಮ್ಮ ಕಾರ್ಯಕ್ಷಮತೆಯನ್ನು ಹೆಚ್ಚಿಸಲು ವ್ಯಾಪಕವಾಗಿ ಬಳಸುತ್ತಿವೆ. ವೈದ್ಯಕೀಯ ಕ್ಷೇತ್ರದಲ್ಲಿ AI ರೋಗ ನಿರ್ಧಾರವನ್ನು ಸುಧಾರಿಸಿದೆ. IBM Watson Health ಅಥವಾ Google DeepMind ನಂತಹ ಸಿಸ್ಟಮ್‌ಗಳು MRI ಮತ್ತು X-ರೇ ಚಿತ್ರಗಳನ್ನು ವಿಶ್ಲೇಷಿಸಿ, ಕ್ಯಾನ್ಸರ್, ಡಯಾಬೆಟಿಸ್ ಅಥವಾ ಹೃದಯ ರೋಗಗಳ ಆರಂಭಿಕ ಸಂಕೇತಗಳನ್ನು ೯೫% ನಿಖರತೆಯೊಂದಿಗೆ ಗುರುತಿಸುತ್ತವೆ. ಇದರಿಂದ ಡಾಕ್ಟರ್‌ಗಳ ಕೆಲಸ ಸುಲಭವಾಗುತ್ತದೆ ಮತ್ತು ರೋಗಿಗಳ ಉಳಿವು ಹೆಚ್ಚುತ್ತದೆ. ಶಿಕ್ಷಣ ಕ್ಷೇತ್ರದಲ್ಲಿ AI ವೈಯಕ್ತಿಕೀಕೃತ ಕಲಿಕೆಯನ್ನು

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(Personalized Learning) ಒದಗಿಸುತ್ತದೆ. Duolingo ಅಥವಾ Khan Academy ಅಪ್‌ಗಳು ವಿದ್ಯಾರ್ಥಿಯ ಕಲಿಕಾ ವೇಗ, ದೌರ್ಬಲ್ಯಗಳು ಮತ್ತು ಆದ್ಯತೆಗಳನ್ನು ವಿಶ್ಲೇಷಿಸಿ, ತಕ್ಕಂತಹ ಪಾಠಗಳನ್ನು ಸೂಚಿಸುತ್ತವೆ. ಇದು ಶಿಕ್ಷಕರಿಗೆ ಸಹಾಯ ಮಾಡುತ್ತದೆ ಮತ್ತು ವಿದ್ಯಾರ್ಥಿಗಳ ಶಿಕ್ಷಣ ಮಟ್ಟವನ್ನು ಹೆಚ್ಚಿಸುತ್ತದೆ. ಉತ್ಪಾದನಾ ಕ್ಷೇತ್ರದಲ್ಲಿ, Tesla ಅಥವಾ Foxconn ನಂತಹ ಕಂಪನಿಗಳು AI ರೋಬೋಟ್‌ಗಳನ್ನು ಬಳಸಿ ಆಟೋಮೇಷನ್ ಮಾಡುತ್ತವೆ, ಇದರಿಂದ ಉತ್ಪಾದಕತೆ ೩೦-೫೦% ಹೆಚ್ಚಾಗುತ್ತದೆ. ಹಣಕಾಸು ಕ್ಷೇತ್ರದಲ್ಲಿ AI ವಂಚನೆ ಗುರುತಿಸುವುದು (Fraud Detection) .ಕೃಷಿ ಕ್ಷೇತ್ರದಲ್ಲಿ ಡ್ರೋನ್‌ಗಳು AI ಮೂಲಕ ಬೆಳೆ ಆರೋಗ್ಯವನ್ನು ಪರೀಕ್ಷಿಸುತ್ತವೆ. ಇದೆಲ್ಲವೂ AI ಯ ಶಕ್ತಿಯನ್ನು ತೋರಿಸುತ್ತದೆ, ಆದರೆ ಇದರ ಸರಿಯಾದ ನಿರ್ವಹಣೆ ಅಗತ್ಯವಾಗಿದೆ.

AI ಯ ಅಪಾಯಗಳು ಮತ್ತು ಗಂಭೀರ ಸವಾಲುಗಳು

AI ಯ ಜೊತೆಗೆ ಗಂಭೀರ ಅಪಾಯಗಳು ಸಹ ಇವೆ, ಇದು ಮಾನವಕುಲದ ಭವಿಷ್ಯವನ್ನು ಅಸ್ಪಷ್ಟಗೊಳಿಸುತ್ತದೆ. ಮೊದಲನೆಯದು ಉದ್ಯೋಗ ನಾಶ: ಆಟೋಮೇಷನ್‌ನಿಂದಾಗಿ ಕಾರ್ಖಾನೆ ಕೆಲಸಗಾರರು, ಡೇಟಾ ಎಂಟ್ರಿ ಆಪರೇಟರ್‌ಗಳು, ಡ್ರೈವರ್‌ಗಳು ಮತ್ತು ಇತರ ರೂಟೀನ್ ಕೆಲಸಗಳು ಕಡಿಮೆಯಾಗುತ್ತಿವೆ. World Economic Forum ನ ೨೦೨೫ರ ವರದಿಯ ಪ್ರಕಾರ, ೮೫ ಮಿಲಿಯನ್ ಉದ್ಯೋಗಗಳು AI ಯಿಂದ ಬದಲಾಗಬಹುದು. ಎರಡನೆಯದು ಮಾನವ ಅವಲಂಬನೆ: AI ಮೇಲೆ ಅತಿಯಾಗಿ ಅವಲಂಬಿಸಿದರೆ, ಮಾನವರ ಚಿಂತನಶೀಲತೆ (Critical Thinking), ಸೃಜನಶೀಲತೆ (Creativity) ಮತ್ತು ಸಮಸ್ಯೆ ಪರಿಹಾರ ಶಕ್ತಿ ಕಡಿಮೆಯಾಗಬಹುದು. ಮೂರನೆಯದು ಗೌಪ್ಯತೆ ಮತ್ತು ಡೇಟಾ ದುರ್ಬಳಕೆ: AI ಲಕ್ಷಾಂತರ ಡೇಟಾವನ್ನು ಸಂಗ್ರಹಿಸುತ್ತದೆ, ಇದು Cambridge Analytica ಸ್ಕ್ಯಾಂಡಲ್‌ನಂತಹ ಘಟನೆಗಳಿಗೆ ಕಾರಣವಾಗಬಹುದು. ನಾಲ್ಕನೆಯದು ಬೈಸ್ (Bias): AI ಮಾಡೆಲ್‌ಗಳು ತರಬೇತಿ ಡೇಟಾದಲ್ಲಿರುವ ಬೈಸ್ ಅನ್ನು ಪುನರಾವರ್ತಿಸುತ್ತವೆ, ಉದಾಹರಣೆಗೆ Amazon ನ ರಿಸ್ಯೂಮ್ ಸ್ಕ್ರೀನಿಂಗ್ ಟೂಲ್ ಮಹಿಳೆಯರ ವಿರುದ್ಧ ಬೈಸ್ ಹೊಂದಿತ್ತು. ಅಂತಿಮವಾಗಿ, ಸೂಪರ್‌ಇಂಟೆಲಿಜೆನ್ಸ್ (Superintelligence) ಅಪಾಯ: AI ಮಾನವ ಬುದ್ಧಿಯನ್ನು ಮೀರಿದರೆ, ಅದು ನಿಯಂತ್ರಣಕ್ಕೆ ಹೊರಬರಬಹುದು. ಇವುಗಳೆಲ್ಲಾ AI ಯ ಜವಾಬ್ದಾರಿಯುತ ಬಳಕೆಯ ಅಗತ್ಯತೆಯನ್ನು ಒತ್ತಿ ಹೇಳುತ್ತವೆ.

ತಜ್ಞರ ಎಚ್ಚರಿಕೆಗಳು ಮತ್ತು ದೃಷ್ಟಿಕೋನಗಳು

AI ಯ ಅಪಾಯಗಳ ಬಗ್ಗೆ ಪ್ರಮುಖ ತಜ್ಞರು ಎಚ್ಚರಿಕೆ ನೀಡಿದ್ದಾರೆ. SpaceX ಮತ್ತು Tesla ನ ಸ್ಥಾಪಕ ಎಲಾನ್ ಮಸ್ಕ್ AI ಅನ್ನು "ನ್ಯೂಕ್ಲಿಯರ್ ಆಯುಧಗಳಿಗಿಂತಲೂ ಹೆಚ್ಚು ಅಪಾಯಕಾರಿ" ಎಂದು ಕರೆದಿದ್ದಾರೆ. ಅವರು OpenAI ಅನ್ನು ಸ್ಥಾಪಿಸಿ AI ಸುರಕ್ಷತೆಗೆ ಒತ್ತು ನೀಡಿದ್ದರು, ಆದರೆ ನಂತರ ಅದರಿಂದ ಬಹಿರಂತರಾದರು. "AI ಯ ಗಾಡ್‌ಫಾದರ್" ಎಂದು ಕರೆಯಲ್ಪಡುವ ಜೆಫ್ರಿ ಹಿಂಟನ್ (Geoffrey Hinton), Google ನಿಂದ ೨೦೨೩ರಲ್ಲಿ ರಾಜೀನಾಮೆ ಮಾಡಿಕೊಂಡು, AI ರೋಬೋಟ್‌ಗಳು ಮತ್ತು ಸೂಪರ್‌ಇಂಟೆಲಿಜೆಂಟ್ ಸಿಸ್ಟಮ್‌ಗಳು ಮಾನವ ನಿಯಂತ್ರಣವನ್ನು ಮೀರಬಹುದೆಂದು ಆತಂಕ ವ್ಯಕ್ತಪಡಿಸಿದ್ದಾರೆ. ಸ್ಟ್ಯಾನ್‌ಫರ್ಡ್‌ನ ಫೆಲುದ್ ಹೆಂಡ್ರಿಕ್ಸ್ AI ಯ ತ್ವರಿತ ಅಭಿವೃದ್ಧಿಯನ್ನು "ಪ್ಯಾಂಡೋರಾ ಬಾಕ್ಸ್" ಗೆ ಹೋಲಿಸಿದ್ದಾರೆ. ಇವರು AI ರೆಸರ್ಚ್‌ನಲ್ಲಿ ಭಾಗವಹಿಸಿದ್ದರೂ, ಜವಾಬ್ದಾರಿಯುತ ನಿಯಂತ್ರಣ ಮತ್ತು ಸುರಕ್ಷತಾ ಪ್ರೋಟಾಕಾಲ್‌ಗಳ ಅಗತ್ಯತೆಯನ್ನು ಒತ್ತಿ ಹೇಳುತ್ತಾರೆ.

೨೦೨೬ರ ಭವಿಷ್ಯದ AI ಟ್ರೆಂಡ್‌ಗಳು

೨೦೨೬ರಲ್ಲಿ AI ಏಜೆಂಟ್‌ಗಳು (Autonomous Agents), ಜನರೇಟಿವ್ AI (Generative AI like GPT-5 ಅಥವಾ DALL-E 4), ಮಲ್ಟಿಮಾಡಲ್ AI (ಟೆಕ್ಸ್ಟ್+ಇಮೇಜ್+ವೀಡಿಯೊ) ಮತ್ತು Explainable AI (XAI) ಟ್ರೆಂಡ್‌ಗಳು ಬೆಳೆಯುತ್ತಿವೆ. ಕ್ವಾಂಟಮ್ ಕಂಪ್ಯೂಟಿಂಗ್‌ನೊಂದಿಗೆ AI ಹೆಚ್ಚಿನ ವೇಗ ಪಡೆಯುತ್ತದೆ. ಇದು ಮಾನವ-AI ಸಹಕಾರವನ್ನು ಹೆಚ್ಚಿಸಬಹುದು, ಉದಾಹರಣೆಗೆ AI ಡಾಕ್ಟರ್‌ಗಳ ಸಹಾಯಕವಾಗಿ ಕೆಲಸ ಮಾಡುತ್ತದೆ. ಆದರೆ EU AI Act ಮತ್ತು USA ನ AI Bill of Rights ನಂತಹ ರೆಗ್ಯುಲೇಷನ್‌ಗಳು ಜಾರಿಯಲ್ಲಿರುತ್ತವೆ.

ನೈತಿಕ ಮಾರ್ಗಸೂಚಿಗಳು ಮತ್ತು ಕೊನೆಯ ಭಾವನೆಗಳು

AI ಅನ್ನು ಸುರಕ್ಷಿತವಾಗಿ ಬಳಸಲು ನೈತಿಕ ಮಾರ್ಗಸೂಚಿಗಳು ಅಗತ್ಯ:

೧) ಬೈಸ್ ತೆಗೆದುಹಾಕುವುದು,

೨) ಡೇಟಾ ಗೌಪ್ಯತೆ ರಕ್ಷಣೆ (GDPR),

೩) ಸುರಕ್ಷತಾ ಆಡಿಟ್‌ಗಳು,

೪) ಮಾನವ ನಿಯಂತ್ರಣ. ಸರ್ಕಾರಗಳು, ಕಂಪನಿಗಳು ಮತ್ತು ಸಮಾಜವು ಸಹಕರಿಸಬೇಕು. AI ಮಾನವಕುಲಕ್ಕೆ ಅಪಾರ ಶಕ್ತಿ ನೀಡುತ್ತದೆ – ರೋಗ ನಿರ್ವಹಣೆಯಿಂದ ಹಿಡಿದು ಜಲವಾಯು ಬದಲಾವಣೆ ಪರಿಹಾರಗಳವರೆಗೆ. ಆದರೆ ಸರಿಯಾದ ಜವಾಬ್ದಾರಿಯಿಂದ ಮಾತ್ರ ಅದು ಕಾರ್ಯಕಾರಿ. ನಾವು AI ಅನ್ನು ಸಾಧನವಾಗಿ ಬಳಸಿ, ಮಾನವೀಯ ಮೌಲ್ಯಗಳನ್ನು ಕಾಪಾಡಿಕೊಳ್ಳಬೇಕು. ಚರ್ಚೆಗೆ ಧನ್ಯವಾದಗಳು. ಪ್ರಶ್ನೆಗಳಿರಲಿ!

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Original Article

Adaptive Strategies of House Sparrows in Response to Urbanization in Coastal Karnataka

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Abstract

Bird species, especially the house sparrow (Passer domesticus), which has traditionally flourished in close proximity to human settlements, have faced serious challenges due to urbanization and rapid habitat modification in coastal Karnataka. When it comes to adjusting to changing ecological niches, sparrows in Mangalore, a city experiencing rapid infrastructure growth, exhibit remarkable behavioral resilience. The adaptive techniques used by sparrows in response to habitat changes, such as fewer nesting locations, changed food sources, and more anthropogenic disturbances, are examined in this study. Field surveys in suburban areas, urban centers, and agricultural zones show that sparrows have adaptable foraging habits, moving from conventional grain-based diets to opportunistic feeding on insects and processed food waste. Their use of unusual locations, including as ventilation ducts, nooks and crannies in contemporary structures, and roadside plants, demonstrates their nesting resilience and helps to offset the loss of traditional hedgerows and tiled roofs. In high-disturbance environments, social behaviors like flocking and communal roosting seem to intensify, indicating group tactics for resource sharing and predator avoidance. The species' reliance on intermediate habitats that strike a balance between ecological resources and human presence is shown by population density patterns, which show higher abundance in semi-urban areas as opposed to agricultural fields. In addition to highlighting their ecological adaptability, Mangalore sparrows' tenacity also suggests their susceptibility to uncontrolled urban growth. In order to maintain sparrow populations, conservation implications highlight the necessity of habitat-sensitive urban development, community awareness, and microhabitat restoration projects. This study highlights sparrows as an indicator of urban ecological health and adds to broader concerns on bird adaptability in rapidly changing landscapes by investigating the behavioral resilience of sparrows in Mangalore.

Keywords: *House sparrow, Mangalore, Nesting resilience, Ecological adaptability, Indicator species.*

Introduction

The House Sparrow (*Passer domesticus*) is one of the most frequent birds in the largest avian order, Passeriformes. The House sparrow's affinity for humans sets it apart from other Passeridae. Because of its strong human association, it was given the scientific name Passer domesticus, which is derived from the Latin word Passer, which means "speed" and refers to small, energetic birds. *Domesticus* is a Latin term meaning "belonging to the house." Males and females are easily distinguished; males have a black bib, a grey crown with chestnut sides, and white cheeks. Females and juveniles have a duskier appearance, and lack the black bib seen in males. Ubiquitous house sparrow is highly urbanized and is among the most prominent birds in the cities and agricultural areas. The house sparrow is also a model species in urban ecology research and on the study of adaptation to human-altered habitats (Riyahi, 2017).

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In spite of a dull brown plumage, it has no inferiority complex instead has the assurance of a peacock and makes its presence all-round the human build-ups be it houses, temples, monuments, market, gardens or agricultural fields. It has long been intertwined with human settlements, thriving in environments shaped by agriculture, architecture, and daily human activity. However, in recent decades, sparrow populations have declined across many regions due to rapid urbanization, pollution, and habitat loss. In India, particularly in coastal Karnataka, circumstantial and scientific observations suggest fluctuating sparrow densities, with urban centres like Mangalore offering a unique case study (Pandian, 2023).

Mangalore's transformation—marked by infrastructure growth, modern housing, and altered food systems—has created ecological challenges for sparrows. Yet, these birds demonstrate remarkable resilience, adapting their foraging, nesting, and social behaviors to survive in modified niches. This paper explores these adaptive strategies, situating sparrows as both victims of urban change and exemplars of ecological flexibility. House sparrow populations in India are facing a critical decline, with up to 88% reduction in Andhra Pradesh and 20% in Kerala, Gujarat, and Rajasthan, potentially leading to extinction, according to ICAR studies. Coastal areas have seen a 70-80% drop due to habitat loss from modern, concrete, closed-design buildings, as well as reduced food availability caused by pesticide use and changes in grain storage.

Modern concrete houses lack the gaps, crevices, and ventilators (nesting sites) present in traditional homes (Waldia& Bhatt, 2022). The shift to sealed packaging and pre-cleaned grains removes easy access to food (Singh et al., 2013). Excessive pesticide use in agriculture drastically reduces the insect population, which is crucial for feeding chicks (Priya et al., 2022). Electromagnetic radiation from mobile towers, air pollution, and climate change are also considered as factors towards dwindling of sparrow's population (Rajendran, 2024).

Sparrows, once listed as "Least Concern" by the IUCN, now face possible endangered status due to rapid population decline. Their disappearance carries ecological consequences, including rising insect numbers that threaten crops and disrupt food chains. Conservation efforts—such as artificial nests, state bird recognition in Delhi and Bihar, and World Sparrow Day celebrations on March 20—aim to restore populations (Mahesh & Lanka, 2021).

Birds are one of the best monitors to detect change in environment condition and have been used to evaluate the environmental condition since ages as a bio-monitor. Birds have long been employed as bio-monitors to assess environmental conditions because they are among the best at seeing changes in the environment. Over half of the world's population currently resides in urban habitats as a result of global urbanization. Urbanization and industrial operations have resulted in the constant introduction of pollutants (Nazneen et al., 2022). There are reports on the use of house sparrow as a model organism to monitor the heavy metals in the atmospheric air (Hamidian et al., 2023).

Studies across Europe and Asia have documented sparrow declines linked to reduced nesting sites, pesticide use, and changes in food availability. In India, researchers highlight urban noise, air pollution, and architectural shifts (from tiled roofs to glass-and-concrete structures) as critical factors (Dandapat et al., 2010; Dhanya&Azeez, 2010; Ghosh et al., 2010; Hussain et al., 2014; Khera et al., 2010; Mahesh & Lanka, 2021; Nath et al., 2019; Paul, 2015; Sharma & Binner, 2020; Singh et al., 2013).

To restore the house sparrow's population status, which is currently needed, a detailed analysis of its behavior and population is necessary.

Methodology

The present study was conducted as a qualitative observation without the maintenance of quantitative datasets. Visual monitoring and casual reasoning formed the basis of the approach. The observations were carried out during the annual Sparrow Day activities organized at the college campus. As part of these activities, leftover food wastes generated on campus were processed using a HERMI composting unit (Black Soldier Fly, Hermetiaillucens L.; Diptera: Stratiomyidae). This composting system provided a continuous supply of insect larvae, which in turn attracted a variety of bird species to the site, including sparrows (*Passer domesticus*).

Subsequently, the composting activity was discontinued, leading to the cessation of larvae production. Following this change, a gradual decline in sparrow presence was noted until their complete disappearance from the site. The correlation between sparrow abundance and the availability of insect larvae was hypothesized based on these visual observations. No quantitative sampling or statistical analysis was performed; instead, the methodology relied on direct observation, documentation of changes in bird presence, and reasoning linked to resource availability.

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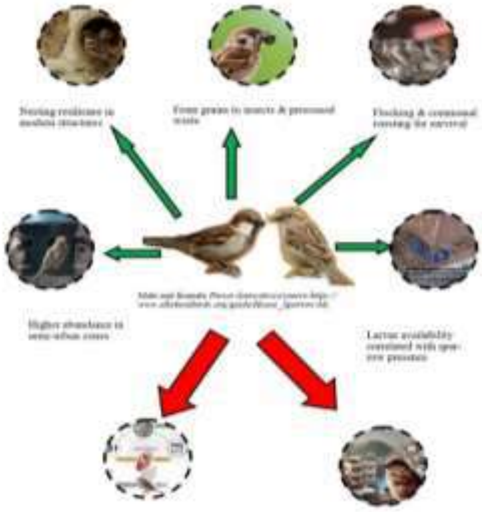

Figure 1. Sparrows as indicators of urban ecological health. Arrows showing Resilience vs. Vulnerability: Green arrow: “Adaptive strategies”; Red arrow: “Threats from urbanization (pollution, habitat loss)”

Results

Sparrows shifted from grain-based diets to opportunistic feeding on insects, crumbs, and processed food waste. In urban centers, sparrows were frequently observed near bakeries, restaurants, and garbage bins. Agricultural zones showed reduced sparrow presence, possibly due to pesticide use and mechanized farming. Visual observations indicated that sparrows (*Passer domesticus*) were frequently present in the college premises during the period when HERMI composting (Black Soldier Fly, Hermetiaillucens L.) was actively maintained. The composting unit generated a continuous supply of insect larvae, which appeared to serve as a readily available food source for several bird species. Sparrows were consistently noted among these visitors, suggesting a positive association between the composting activity and sparrow abundance. Following the discontinuation of HERMI composting, a gradual decline in sparrow sightings was observed. Over time, sparrows disappeared entirely from the study site. This disappearance was temporally correlated with the cessation of larvae production, leading to the hypothesis that sparrow presence was influenced by the availability of insect larvae as a food resource. The findings highlight the potential ecological role of composting systems in supporting local avifauna by providing supplementary food sources. While the observations were qualitative and lacked quantitative data, the pattern suggests that resource availability may directly influence sparrow populations in localized habitats. This aligns with ecological principles where food abundance is a critical determinant of species distribution and persistence. However, the absence of systematic data collection limits the ability to establish causality, and further controlled studies are required to validate the hypothesized relationship.

Discussion

The house sparrows thought once as economically menacing bird species and efforts were planned to regulate their populations (Southern, 1945). But now their population size is declining in India (Dandapat et al., 2010; Sharma & Binner, 2020). The sparrows of Mangalore exemplify resilience through behavioral plasticity. Their ability to exploit new food sources and nesting sites reflects evolutionary flexibility. However, reliance on anthropogenic waste raises concerns about nutritional quality and long-term health (Caspi et al., 2022). Despite adaptability, sparrows remain vulnerable to unchecked urban expansion. Loss of vegetation, increased pollution, and architectural homogenization threaten their survival. Semi-urban niches may serve as temporary refuges, but without deliberate conservation, populations could decline further (Shaw et al., 2008). Sparrows’ fluctuating densities mirror broader ecological shifts. Their presence—or absence—signals the health of urban ecosystems. Monitoring sparrows can thus inform biodiversity-sensitive urban planning. There are many reports where the organic wastes converted into high-quality nutrients for pet food, fish and poultry feed, and residual fertilizer for soil amendment by black soldier fly larvae (BSFL), (Sheppard et al., 1994) Hermetia (Barragan-Fonseca et al., 2017; Bessa et al., 2020; Diener, StudtSolano, et al., 2011; Diener, Zurbrügg, et al., 2011; Dörper et al., 2021; Sheppard et al., 1994, 2002; Tomberlin et al., 2009; van Huis et al., 2020; Wang &Shelomi, 2017). Integrating conservation strategies with existing urban planning frameworks can enhance habitat quality for house sparrows, promoting population recovery and resilience in urban areas across India (Dhar et al., 2025).

Conclusion

The house sparrow in Mangalore embodies both resilience and fragility in the face of urbanization. Its adaptive strategies—dietary shifts, nesting innovations, and intensified social behaviors—demonstrate ecological plasticity. Yet, these adaptations are not limitless; uncontrolled urban growth poses existential risks. Conservation efforts must prioritize habitat-sensitive development, community engagement, and microhabitat restoration.

By studying sparrows, we gain insights into the broader dynamics of avian adaptability in rapidly changing landscapes. Their survival is not merely an ecological concern but a reflection of how human societies coexist with biodiversity.

The observations suggest a strong correlation between the presence of sparrows (*Passer domesticus*) and the operation of HERMI composting units that produced Black Soldier Fly (*Hermetiaillucens*) larvae. During active composting, sparrows were regularly observed, likely benefiting from the abundant food resource. Following the discontinuation of composting and the consequent reduction in larvae availability, sparrow sightings declined and eventually ceased.

Although the study was qualitative and based solely on visual observations, the findings highlight the potential ecological significance of composting systems in supporting local bird populations. The results underscore the importance of resource availability in shaping species presence within microhabitats. Future studies incorporating systematic data collection, quantitative monitoring, and controlled experiments are necessary to validate these preliminary observations and to better understand the role of composting practices in avian ecology.

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Original Article

Prevalence and Determinants of Diabetes in Rural and Semi-Rural Communities of Nippani, Karnataka, India

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Abstract

Diabetes mellitus is a growing public health concern in rural India, driven by demographic transition, lifestyle changes, and genetic predisposition. This study aimed to assess the prevalence and determinants of diabetes in rural and semi-rural communities of Nippani, Karnataka. A community-based cross-sectional study was conducted among 100 adults aged ≥29 years. Data collected included demographic variables, fasting blood sugar (FBS), postprandial blood sugar (PBS), and family history of diabetes. Results revealed a higher prevalence among females (69%) compared to males (31%). A strong association was observed between positive family history and diabetes occurrence (42%). Blood sugar analysis showed that most participants had elevated PBS values (74 cases in the 201–300 mg/dl range). Village-level analysis indicated higher prevalence in Nippani town, Mamadapur, and Ugar, likely due to sedentary occupations and dietary transitions. The findings highlight the urgent need for early screening, lifestyle interventions, and strengthened primary healthcare systems in rural India.

Keywords: *Diabetes mellitus, rural health, prevalence, determinants, Karnataka.*

Introduction

Diabetes mellitus (DM) is a chronic metabolic disorder characterized by hyperglycemia resulting from defects in insulin secretion, insulin action, or both. According to the International Diabetes Federation (IDF), India is among the countries with the highest number of adults living with diabetes. Rapid urbanization, sedentary lifestyle, dietary transitions, and population aging have contributed significantly to its rising prevalence. Traditionally considered an urban disease, diabetes is increasingly affecting rural populations. Rural communities are experiencing lifestyle shifts, including decreased physical activity and increased consumption of processed foods. Moreover, limited healthcare access in rural settings contributes to delayed diagnosis and complications. Karnataka has reported increasing diabetes prevalence across both urban and rural areas. However, micro-level data from semi-rural regions like Nippani remain limited. This study aims to assess the prevalence and determinants of diabetes in selected rural and semi-rural communities of Nippani.

Objectives:

1. To determine the prevalence and determinants of diabetes among adults in rural and semi-rural communities of Nippani.
2. To estimate the prevalence of diabetes based on blood glucose levels.
3. To examine the association between age and diabetes.
4. To assess gender differences in diabetes prevalence.
5. To evaluate the role of genetic (family) history as a determinant.
6. To compare prevalence across villages and semi-urban areas. To determine the prevalence and determinants of diabetes among adults in rural and semi-rural communities of Nippani.
7. To estimate the prevalence of diabetes based on blood glucose levels.

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10. To examine the association between age and diabetes.
11. To assess gender differences in diabetes prevalence.
12. To evaluate the role of genetic (family) history as a determinant.
13. To compare prevalence across villages and semi-urban areas.

Materials and Methods
Study Design: Community-based cross-sectional study.
Study Area: Rural and semi-rural villages surrounding Nippani, Karnataka, including Mamadapur, Gayakanwadi, Jainwadi, Mugali, Ugar, Pattanakudi, Akkol, and others.
Study Population: Random, Adults aged 29–86 years residing in the selected communities.

Sample Size: 100
Data collected included:

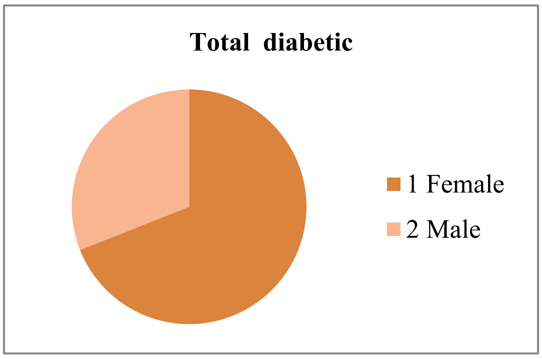
- Age
- Gender
- Place of residence
- Fasting Blood Sugar (FBS)
- Postprandial Blood Sugar (PBS)
- Family history of diabetes

Data Analysis
Data were analyzed using descriptive statistics. Prevalence was calculated as percentage. Determinants were assessed through subgroup comparisons.

Results

Gender Distribution

Sl. No	Gender	Total diabetic
01	Female	69
02	Male	31



- Female diabetics: 69%
- Male diabetics: 31%
- **Finding:** Diabetes prevalence was significantly higher among females.

Family History

Sl. No	Genetic history	Total
01	Yes	42
02	No	58

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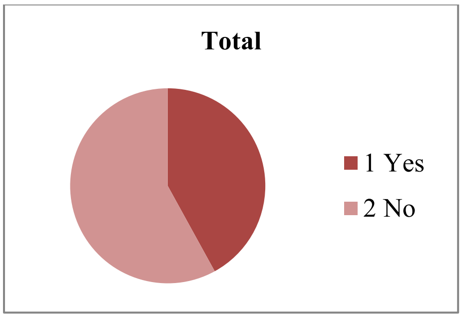
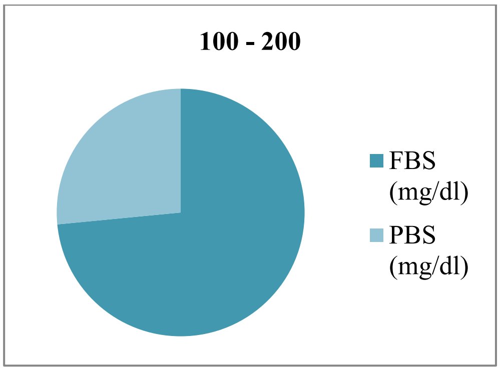
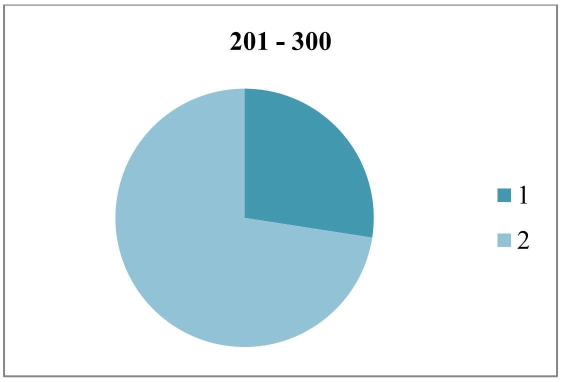


- Positive family history: 42%
- No family history: 58%
- **Finding:** Strong association between family history and diabetes prevalence.

Blood Glucose Ranges

Range	FBS (mg/dl)	PBS (mg/dl)
100 - 200	72	26
201 - 300	28	74





Finding: Elevated PBS values were more common, indicating poor glycemic control.
Possible contributing factors:

- Sedentary occupation
- Dietary transition
- Reduced physical activity

Discussion

The present study shows a diabetes prevalence of female 69%, which is significantly higher than national rural averages reported in previous studies (typically 8–15%). This may reflect:

- Targeted screening of high-risk adults
- Small sample size
- Older population representation

Consistent with national trends, increasing age was strongly associated with diabetes. Genetic predisposition significantly increased risk. Female predominance may reflect hormonal, lifestyle, or health-seeking behavior differences.

Rural areas are no longer protected from non-communicable diseases. Transition in food habits and reduced physical labor may explain rising rural diabetes.

Conclusion

The prevalence of diabetes in rural and semi-rural communities of Nippani, Karnataka, is alarmingly high.

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Key determinants identified:

- Increasing age
- Female gender
- Positive family history

Early screening programs, health education, lifestyle modification initiatives, and strengthened primary healthcare systems are urgently required.

Recommendations

1. Regular village-level screening camps
2. Health education on diet and exercise
3. Strengthening PHC-based diabetes management
4. Community awareness programs
5. Further large-scale epidemiological studies

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Original Article

Spatial Variation in Fruit Preference of *Drosophila* spp. Across Urban Microhabitats: Evidence for Behavioural Resilience in Changing Environments

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Abstract

Urbanization creates heterogeneous environments that impose novel ecological challenges on organisms, requiring adaptive behavioural responses for persistence. Behavioural resilience, particularly in foraging strategies, plays a crucial role in enabling species to cope with such environmental variability. The present study examines spatial variation in fruit preference of Drosophila species across three urban microhabitats—Rajajinagar, Prakashnagar, and Gayathrinagar—characterized by differing levels of anthropogenic disturbance. Four commonly available fruits (banana, orange, papaya, and watermelon) were simultaneously exposed at each site, and the relative attraction of Drosophila individuals was recorded and analyzed as percentage preference. Results revealed marked differences in fruit selection among locations, with banana and orange showing higher attraction in Prakashnagar, equal preference for orange and papaya in Rajajinagar, and intermediate patterns in Gayathrinagar. Watermelon consistently exhibited the lowest attraction across all sites. These findings indicate that foraging behaviour in Drosophila is influenced by local environmental conditions, likely mediated through variations in olfactory cues and microbial fermentation. The observed behavioural plasticity underscores the capacity of Drosophila species to adjust resource use in response to urban microhabitat heterogeneity, contributing to their ecological resilience in rapidly changing environments.

Keywords: *Drosophila spp.; urban microhabitats; fruit preference; foraging behaviour; behavioural plasticity; ecological resilience; urban ecology.*

Introduction

Anthropogenic environmental change, particularly urbanization, significantly alters habitat structure, temperature regimes, resource distribution, and microbial composition (Grimm et al., 2008). Species persistence in such environments depends not only on physiological tolerance but also on behavioural flexibility (Sih et al., 2011).

Behavioural resilience refers to the ability of organisms to adjust behavioural responses to environmental disturbances while maintaining survival and reproductive success (Wong & Candolin, 2015). Insects, due to their short life cycles and rapid behavioural responses, provide valuable systems for studying resilience mechanisms.

Fruit flies (*Drosophila* spp.) are well-established model organisms in behavioural ecology. Their foraging decisions are largely mediated by olfactory cues associated with microbial fermentation (Becher et al., 2012). Studies have demonstrated that behavioural traits and fitness parameters vary among *Drosophila* species, reflecting adaptive potential (Kudupali &Shivanna, 2013). Phenotypic plasticity theory further suggests that flexible behavioural responses facilitate successful colonization of novel environments (West-Eberhard, 2003; Yeh & Price, 2004).

Given the heterogeneity of urban microhabitats, examining fruit preference across spatially distinct localities provides insight into behavioural adjustments under changing environmental conditions.

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Materials And Methods

Study Sites

The study was conducted in three urban localities:

- Rajajinagar
- Prakashnagar
- Gayathrinagar

These sites differ in vegetation cover, waste disposal patterns, and levels of anthropogenic disturbance, thereby representing distinct microhabitats.

Fruit Selection and Experimental Setup

Four commonly available fruits were selected:

- Banana (*Musa paradisiaca*)
- Orange (*Citrus sinensis*)
- Papaya (*Carica papaya*)
- Watermelon (*Citrullus lanatus*)

Equal quantities of ripe fruit were exposed simultaneously in open containers at each site. Observations were conducted during similar environmental conditions to minimize temporal bias.

Data Collection and Analysis

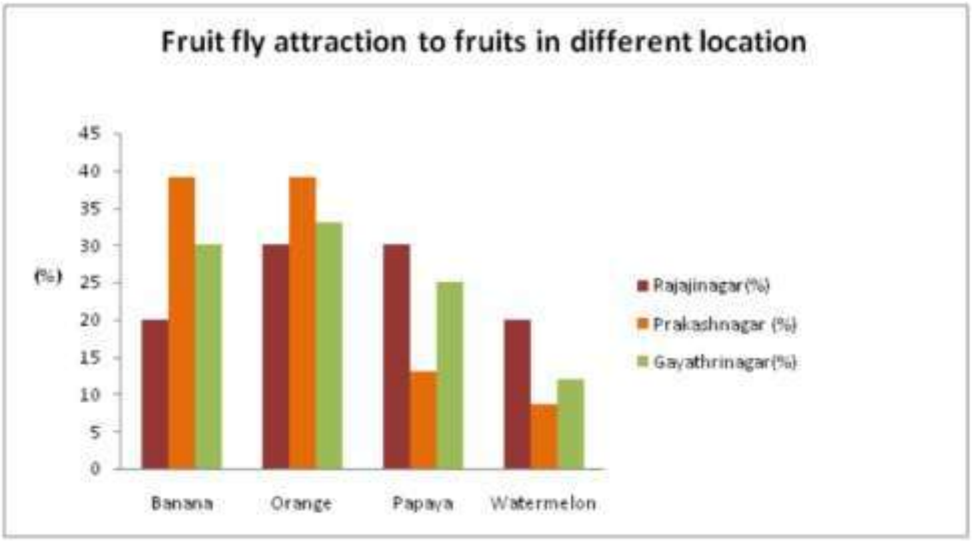
The number of *Drosophila* individuals attracted to each fruit was recorded. Data were converted into percentage attraction per fruit type per locality. Comparative descriptive analysis was used to identify spatial variation.

Results

Fruits	Rajajinagar (%)	Prakashnagar (%)	Gayathrinagar (%)
Banana	20.0	39.13	30.0
Orange	30.0	39.13	33.0
Papaya	30.0	13.04	25.0
Watermelon	20.0	8.70	12.0

Distinct differences were observed across sites. Prakashnagar showed strong preference for banana and orange, while Rajajinagar exhibited equal preference for orange and papaya. Gayathrinagar displayed intermediate attraction patterns.

Graph 1: Drosophila flies Attracted to different fruits at different locations



Distinct differences were observed across sites. Prakashnagar showed strong preference for banana and orange, while Rajajinagar exhibited equal preference for orange and papaya. Gayathrinagar displayed intermediate attraction patterns.

Discussion

Spatial Variation in Foraging Behaviour

The observed differences in fruit preference among urban microhabitats indicate habitat-specific behavioural responses. Resource selection was not uniform across sites, suggesting that local environmental factors influence foraging decisions. Urban heterogeneity is known to shape wildlife behaviour and resource use (Lowry et al., 2013; Sol et al., 2013).

Role of Olfactory Cues and Microbial Mediation

Attraction to fruit substrates in Drosophila is strongly influenced by volatile compounds produced during microbial fermentation (Becher et al., 2012; Rohlfs & Hoffmeister, 2003). Variations in microbial communities across sites may explain differences in fruit attractiveness. Lower attraction to watermelon across all locations may reflect reduced fermentation-derived volatiles.

Genetic variation in olfactory behaviour has also been documented in Drosophila populations (Fiumera et al., 2005), suggesting that both environmental and intrinsic factors contribute to foraging plasticity.

Behavioural Plasticity and Resilience

Behavioural plasticity allows organisms to respond flexibly without requiring genetic change (West-Eberhard, 2003). Theoretical frameworks highlight both the benefits and costs of plasticity (DeWitt et al., 1998). In urban ecosystems characterized by unpredictability, flexible foraging enhances survival probability (Yeh & Price, 2004).

Studies on behavioural adaptation under rapid environmental change emphasize that species with flexible behavioural repertoires are more resilient (Sih et al., 2011). Research by Kudupali & Shivanna (2013) demonstrates interspecific variation in fitness traits within Drosophila, further supporting adaptive potential in this genus.

Ecological Implications

Urban ecosystems represent novel selective environments (Grimm et al., 2008). Behavioural adjustments often precede evolutionary adaptation (Sol et al., 2013). The capacity of Drosophila to shift fruit preference across microhabitats reflects a generalist strategy that buffers populations against environmental instability.

Understanding such resilience mechanisms is essential for predicting species responses to ongoing habitat modification and climate change.

Conclusion

The present study demonstrates clear spatial variation in fruit preference of Drosophila spp. across three urban microhabitats. The findings indicate flexible foraging behaviour influenced by local environmental conditions. Such behavioural plasticity likely enhances ecological resilience in heterogeneous and rapidly changing habitats. These results contribute to broader understanding of adaptive behavioural strategies in urban ecosystems.

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Original Article

Genomic Tools for Species Conservation

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Abstract

The accelerating decline of global biodiversity poses a serious threat to ecosystem functioning and long-term environmental sustainability. While conventional conservation strategies based on ecological surveys and morphological identification have contributed significantly to species protection, they often fail to capture underlying genetic variation critical for species persistence. Advances in genomic technologies have transformed conservation biology by enabling detailed analyses of genetic diversity, population structure, evolutionary history, and adaptive capacity. Tools such as DNA barcoding, microsatellites, single nucleotide polymorphisms (SNPs), restriction site-associated DNA sequencing (RAD- seq), whole-genome sequencing (WGS), and environmental DNA (eDNA) support accurate species identification, population monitoring, and evidence-based conservation decision- making. This review paper synthesizes major genomic tools used in species conservation, highlights their applications, and discusses associated challenges, ethical considerations, and emerging trends for integrating genomics into conservation policy and practice.

Keywords: *Global biodiversity; Genomic technologies; Species conservation; Environmental DNA (eDNA); Biodiversity sustainability.*

Introduction

Biodiversity underpins the stability, productivity, and resilience of ecosystems by sustaining vital ecological processes such as nutrient cycling, pollination, climate regulation, and trophic interactions. These processes are essential not only for ecosystem health but also for human survival and economic well-being. Despite its critical importance, biodiversity is experiencing unprecedented decline worldwide. Human-driven factors—including habitat loss and fragmentation, climate change, pollution, overexploitation of natural resources, and biological invasions—have dramatically accelerated species extinctions, with current rates far exceeding natural background levels (Spielman et al., 2004; Frankham et al., 2010).

Conservation biology has traditionally relied on ecological field surveys, population censuses, and morphological taxonomy to assess species status and inform management decisions. Although these methods remain fundamental, they often provide limited insight into the genetic processes that influence long-term population viability. Genetic diversity is a key component of biodiversity because it determines a population's ability to adapt to environmental change, resist pathogens, and maintain reproductive fitness (Frankham et al., 2010). Populations with reduced genetic variation are more vulnerable to inbreeding depression, accumulation of harmful mutations, and loss of adaptive potential, particularly when populations are small or geographically isolated. Recent advances in genomic technologies have fundamentally reshaped conservation science by enabling genome-wide investigation of genetic variation across individuals and populations.

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Conservation genomics combines molecular genetics, next-generation sequencing, and bioinformatics with ecological data to provide high-resolution insights into population structure, gene flow, demographic history, and adaptive evolution (Allendorf etal., 2010; Ellegren, 2014). These tools facilitate accurate species identification, detection of cryptic species, and continuous biodiversity monitoring, all of which are essential for effective conservation planning.

Beyond traditional population genetics, genomic applications now extend to wildlife forensics, monitoring of illegal wildlife trade, assessment of climate-related adaptive traits, and evaluation of conservation interventions. As sequencing technologies become more affordable and accessible, genomics is increasingly incorporated into conservation policy and management frameworks. By enabling precise characterization and long-term monitoring of genetic diversity, genomic tools play a vital role in enhancing the resilience and adaptive capacity of species in rapidly changing environments. This review examines the major genomic tools used in species conservation, their applications and limitations, and emerging directions that are shaping the future of biodiversity conservation.

Conservation Genomics: An Overview

Conservation genomics is an interdisciplinary field that applies genome-scale data to address critical challenges in biodiversity conservation. It expands upon traditional conservation genetics by utilizing high-throughput sequencing technologies to examine thousands to millions of genetic markers across the genome, rather than focusing on a limited number of loci (Allendorf et al., 2010). This genome-wide perspective provides a more comprehensive understanding of genetic variation, population structure, and evolutionary processes influencing species survival.

A central objective of conservation genomics is to support informed conservation and management decisions by quantify inggenetic diversity, identifying biologically meaningful conservation units, and assessing population connectivity. Genetic diversity is essential for population persistence because it enhances adaptive potential, disease resistance, and reproductive success. Genomic analyses enable precise estimation of genetic variation within and among populations, helping to identify populations at risk from inbreeding, genetic drift, or restricted gene flow (Frankham et al., 2010).

Advances in next-generation sequencing have greatly expanded genomic research to include non-model and endangered species that previously lacked genetic resources. Approaches such as SNP genotyping, reduced-representation sequencing, and whole-genome sequencing allow reconstruction of demographic history, detection of population bottlenecks, and identification of adaptive genetic variation (Ellegren, 2014). These insights are criticalfor understanding how species respond to habitat fragmentation, climate change, and other anthropogenic pressures.

Conservation genomics also plays a key role in defining Evolutionarily Significant Units (ESUs) and Management Units (MUs), which form the scientific basis for conservation prioritization and policy decisions. By integrating genomic data with ecological and environmental information, conservation genomics supports evidence-based strategies suchas habitat restoration, captive breeding, genetic rescue, and reintroduction programs.

Genomic Tools Used in Species Conservation

The rapid development of genomic technologies has provided conservation biologists with a diverse set of tools for investigating genetic variation, population processes, and adaptive potential across a wide range of taxa. These tools differ in genomic coverage, resolution, cost, and analytical requirements, making them suitable for different conservation objectives. Selection of an appropriate genomic approach depends on factors such as research questions, availability of reference genomes, sample quality, and management priorities (Allendorf et al., 2010; Ellegren, 2014).

DNA Barcoding and Metabarcoding

DNA bar coding enables species identification using short, standardized genetic markers that show sufficient variation among species but remain relatively conserved within species. In animals, the mitochondrial cytochrome c oxidase I (COI) gene is most commonly used, whereas plant and fungal barcoding relies on chloroplast genes (rbcL, matK) and the internal transcribed spacer (ITS) region, respectively (Hebert et al., 2003).

In conservation contexts, DNA barcoding is particularly valuable for identifying morphologically ambiguous specimens, early life stages, degraded samples, and processed biological materials. It is widely applied in biodiversity inventories, detection of cryptic species, monitoring of invasive taxa, and identification of illegally traded wildlife products (Ogden & Linacre, 2015). When combined with high-throughput sequencing, metabarcoding allows simultaneous identification of multiple species from mixed or environmental samples, greatly enhancing large-scale biodiversity assessments (Taberlet et al., 2018).

Micro satellite Markers

Microsatellites, or simple sequence repeats (SSRs), are short, repetitive DNA motifs distributed throughout the genome that exhibit high allelic variability. Due to their codominantin heritance and high

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mutationrates, microsatellites have been extensively used in conservation genetics to estimate genetic diversity, assess population structure, infer gene flow, and determine parentage (Frankham et al., 2010).

These markers have been particularly useful for studying small or fragmented populations, where fine-scale resolution of genetic relationships is required. However, microsatellite analyses are limited by labor-intensive marker development, challenges in cross-species transferability, and restricted genomic coverage. As a result, they are increasingly complemented or replaced by SNP-based approaches that provide higher genomic resolution (Allendorf et al., 2010).

Single Nucleotide Polymorphisms (SNPs)

Single nucleotide polymorphisms (SNPs) are single-base variations distributed abundantly across the genome and represent a stable and highly informative class of genetic markers. Advances in next-generations equencing have enabled the discovery and genotyping of thousands to millions of SNPs, even in non-model organisms (Ellegren, 2014). In conservation genomics, SNP data are widely used to characterize population structure, estimate effective population size, detect inbreeding and admixture, and identify loci associated with local adaptation. Their genome-wide distribution and suitability for high- throughput analysis make SNPs particularly effective for defining Evolutionarily Significant Units (ESUs) and Management Units (MUs), which are central to conservation planning and policy development (Allendorf et al., 2010).

Restriction Site–Associated DNA Sequencing (RAD-seq)

RAD-seq is a reduced-representation sequencing method that targets genomic regions adjacent to restriction enzyme cut sites, generating thousands of SNPs across consistent portions of the genome. This approach allows population-scale genomic analysis without the need for a complete reference genome, making it especially valuable for threatened and non- model species (Baird et al., 2008).

RAD-seq has been widely applied in conservation research to examine population differentiation, phylogeographic structure, gene flow, and signatures of local adaptation. Its relatively low cost and scalability enable comparative analyses across large numbers of individuals, supporting conservation decisions related to population connectivity, adaptive management, and restoration planning.

Whole-Genome Sequencing (WGS)

Whole-genome sequencing provides the most comprehensive view of genetic variation by capturing information from both coding and non-coding regions of the genome. This approach allows detailed assessment of genetic diversity, mutation load, inbreeding levels, historical demography, and selective processes operating across the genome (Ellegren, 2014). In conservation genomics, WGS has become increasingly feasible due to declining sequencing costs and advances in bioinformatics. It has been applied to identify deleterious mutations in small populations, quantify genome-wide inbreeding depression, and compare adaptive potential across populations and related species. Such insights are critical for managing endangered species and developing long-term, evidence-based conservation strategies (Frankham et al., 2010).

Environmental DNA (eDNA)

Environmental DNA refers to genetic material released by organisms into their surroundings through biological processes such as shedding of skin cells, excretion, or reproduction. This DNA can be recovered from environmental samples, including water, soil, or sediments, without the need to capture or directly observe organisms (Taberlet et al.,2018).

eDNA analysis has emerged as a powerful non-invasive tool for detecting rare, elusive, or aquatic species and for monitoring biodiversity over large spatial scales. It is particularly effective for early detection of in vasive species, assessment of species

distributions, and long-term ecosystem monitoring, thereby supporting cost-effective and minimally disruptive conservation practices.

Genome Skimming

Genome skimming involves low-coverage sequencing of whole genomes to recover high-copy-number regions such as mitochondrial DNA, chloroplast DNA, and ribosomal RNA genes. This cost-effective approach is especially useful for species identification, phylogenetic analysis, and evolutionary studies in plants and non-model organisms. In conservation research, genome skimming supports rapid generation of genetic data for poorly studied taxa and facilitates comparative analyses across populations and species, contributing to taxonomic clarification and biodiversity assessment.

Target Capture Sequencing

Target capture sequencing selectively enriches predefined genomic regions—such as exons or ultra conserved elements (UCEs)—prior to sequencing. This method enables comparison of homologous genomic regions across individuals and taxa, making it well suited for phylogenomics, population genetics, and studies of adaptive variation. Because target capture balances genomic resolution with cost efficiency, it is increasingly used

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in conservation studies that require standardized datasets across multiple species or populations.

Transcriptomics (RNA-seq)

Transcriptomic approaches analyze gene expression patterns under specific environmental or physiological conditions. In conservation biology, RNA sequencing (RNA- seq) is used to investigate molecular responses to stressors such as temperature extremes, pollution, disease, and habitat degradation.

Byidentifying genes associated with stress tolerance and adaptive responses, transcriptomics provides insights into the functional mechanisms underlying resilience and vulnerability, complementing DNA-based genomic analyses.

Metagenomics

Metagenomics involves sequencingDNA from entire biological communities rather than individual organisms. This approach is widely applied to study soil biodiversity, aquatic microbial communities, host-associated microbiomes, and overall ecosystem health.

In conservation contexts, metagenomic data help elucidate species interactions, ecosystem functioning, and the effects of environmental change, supporting ecosystem-level conservation and restoration efforts.

Epigenetic Approaches

Epigenetic analyses focus on heritable changes in gene regulation, such as DNA methylation, that occur without altering the underlying DNA sequence. These mechanisms play an important role in phenotypic plasticity and rapid responses to environmental stress.

Epigenetic tools offer emerging opportunities to understand how populations cope with environmental change over short timescales, providing an additional layer of information beyond genetic variation alone.

CRISPR-Based Genomic Technologies

Genome-editing technologies such as CRISPR-Cas systems are being explored experimentally for applications in conservation, including genetic rescue, disease resistance, and control of invasive species. However, their use remains highly controversial due to ethical, ecological, and governance concerns.

At present, CRISPR-based tools are primarily of theoretical and experimental interestin conservation, and their deployment requires careful risk assessment and societal debate.

Ancient DNA (aDNA) Analysis

Ancient DNA techniques enable recovery of genetic material from historical specimens, museum collections, and fossil remains. These data provide insights into past genetic diversity, population declines, and evolutionary trajectories.

In conservation planning, aDNA analyses help establish historical baselines and inform reintroduction and restoration programs by revealing how modern populations differ from their ancestral counterparts.

Table1: Summary of Genomic Tools Used in SpeciesConservation

Genomic Tool	Genomic Coverage	Primary Applications in Conservation	Key Advantages	Limitations
DNA barcoding	Single gene region	Species identification, cryptic species detection, wildlife	Rapid, cost- effective, standardized	Limited resolution for population-level

Genomic Tool	Genomic Coverage	Primary Applications in Conservation	Key Advantages	Limitations
		forensics		studies
Metabarcoding	Multiple species markers	Community-level biodiversity assessment, invasive species detection	High-throughput, non-invasive	PCR bias, reference database dependence
Microsatellites	Multiple short loci	Genetic diversity, parentage, gene flow analysis	High polymorphism, codominant markers	Labor-intensive, limited genomic coverage
SNP genotyping	Genome-wide (distributed loci)	Population structure, inbreeding, adaptive variation	Highresolution, scalable	Requires bioinformatics expertise
	Reduced-	Population differentiation,	No reference	Missing data,

RAD-seq	representation genome-wide	phylogeography, local adaptation	genome required, cost-efficient	enzyme choice bias
Whole-genome sequencing	Entiregenome	Inbreeding, mutation load, demographic history	Comprehensive genetic insight	High cost, computational demands
eDNA analysis	Environmental samples	Species detection, ecosystem monitoring	Non-invasive, sensitive	DNA degradation, false positives
Genome skimming	High-copy genomic regions	Phylogenetics, species identification	Rapid, low-cost	Limited functional insight
Targetcapture sequencing	Selected genomic regions	Comparative genomics, adaptive loci identification	Cost–resolution balance	Probe design dependency
Transcriptomics (RNA-seq)	Expressed genes	Stress response, adaptive mechanisms	Functional insights	Tissue- and time-specific
Metagenomics	Community DNA	Ecosystem health, species interactions	Holistic ecosystem view	Complex data interpretation
Epigenetic analyses	Regulatory modifications	Phenotypicplasticity, rapid adaptation	Captures non-geneticadaptation	Methodological complexity
CRISPR-based tools	Targeted genome editing	Genetic rescue, invasive species control	High precision	Ethical and ecological concerns
Ancient DNA (aDNA)	Historical genomes	Baseline genetic diversity, past demography	Long-term evolutionary insight	DNA degradation, contamination risk

Applications of Genomic Tools in Species Conservation

Advances in genomic technologies have revolutionized conservation biology by enabling detailed insights into genetic variation, population dynamics, and adaptive potential of species. These tools provider obust scientific evidence for designing effective conservation strategies, particularly for threatened and endangered species facing habitat loss, climate change, and anthropogenic pressures.

Assessment of Genetic Diversity

Genetic diversity forms the biological foundation for species survival, adaptability, and evolutionary potential. Genomic tools such as whole-genome sequencing, single nucleotide polymorphism (SNP) analysis, and microsatellite markers allow precise assessment of genetic variation within and between populations. Low genetic diversity often indicates inbreeding, reduced fitness, and increased vulnerability to diseases and environmental stressors. By identifying genetically impoverished populations, conservationists can implement genetic rescue programs, translocations, and scientifically managed captive breeding initiatives to restore genetic health and enhance long-term population viability.

Population Structure and Connectivity

Understanding population structure and gene flow is critical for managing species in fragmented landscapes. Genomic analyses reveal patterns of population subdivision, levels of connectivity, and barriers to dispersal caused by natural or human-made obstacles such as roads, dams, and urban expansion. These insights help determine whether populations function as isolated units or as part of a metapopulation network. Such information is invaluable for habitat restoration planning, designing wildlife corridors, and maintaining ecological connectivity essential for gene exchange and population stability.

Identification of Conservation Units

Genomic data play a pivotal role in identifying Evolutionarily Significant Units (ESUs) and Management Units (MUs), which form the basis of modern conservation planning. By uncovering deep genetic divergence and local adaptations, genomics ensures that distinct evolutionary lineages are recognized and protected. This approach prevents the loss of unique genetic traits, especially in widely distributed species exhibiting regional adaptations. Accurated elineation of conservation unit senablestargeted management practices and prevents inappropriate mixing of genetically distinct populations.

Demographic History and Population Bottlenecks

Genomic tools allow reconstruction of historical population sizes and demographic events, including population bottlenecks, expansions, and long-term declines. By analyzing genomic signatures such as linkage

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disequilibrium and allele frequency patterns, researchers can infer past disturbances like habitat destruction, overexploitation, or climatic shifts. Understanding demographic history helps assess current extinction risks and provides a predictive framework for future population trends, thereby supporting proactive and evidence-based conservation decision-making.

Adaptation to Climate Change

Climate change presents one of the most pressing threats to global biodiversity. Genomic studies help identify genes and genomic regions associated with adaptivetraits such as thermal tolerance, drought resistance, reproductive timing, and disease immunity. Populations exhibiting high adaptive genetic variation can be prioritized for conservation, assisted migration, or selective breeding programs. Integrating genomics into climate- responsive conservation strategies enhances the ability of species to cope with rapidly changing environmental conditions.

Wildlife Forensics and Law Enforcement

Genomic tools have become powerful instruments in wildlife forensics and conservation law enforcement. DNA-based techniques enable accurate identification of species, individuals, and geographic origin of confiscated wildlife products such as skins, bones, horns, and meat. This scientific evidence strengthens legal prosecutions, deters illegal wildlife trade, and supports international conservation agreements. By bridging science and policy, genomics significantly contributes to the protection of biodiversity and enforcementof wildlife conservation laws.

Case Studies of Genomic Tools in Species Conservation

1. **Florida Panther– GeneticRescue**

Severe in breeding reduced the Florida panther (Puma concolor coryi) population to fewer than 30 individuals, causing low heterozygosity and congenital defects. Microsatellite andmtDNAanalysesguidedthe1995 translocation of Texa scougars (Pumaconcolor
stanleyana) to restore gene flow. Subsequent genomic monitoring showed increased genetic diversity, improved survival, and population recovery to over 200 individuals, making it a landmark case of genomics-guided conservation (Johnson et al., 2010).

Mountain Gorilla–Genome-Based Population Assessment

Whole-genome sequencing of mountain gorillas (Gorilla beringei beringei) revealed long-term inbreeding but also e vidence of purging deleterious mutations and retention of adaptive variation. These insights refined extinction risk assessments and supported habitat protection and connectivity strategies (Xue et al., 2015).

African Elephant–Wildlife Forensic Genomics

Microsatellite and SNP-based genetic reference maps enabled tracing of seized ivoryto specific geographic regions across Africa. This genomic forensic approach identified poaching hotspots and strengthened international enforcement efforts against illegal ivory trade (Wasser et al., 2004; 2015).

Tasmanian Devil –Disease Resistance Genomics Whole-genome analyses of Tasmanian devils (Sarcophilus harrisii) identified immune-related loci under selection in response to Devil Facial Tumour Disease. Genomic data now guide captive breeding and insurance populations to preserve adaptive potential (Murchison et al., 2012).

Reef-Building Corals–Climate Adaptation Genomics

Genome-wide SNP and transcriptomic studies in corals such as Acropora millepora identified alleles linked to thermal tolerance and stress-response pathways. These findings support assisted gene flow and climate-resilien tree frestoration under global warming (Dixon et al., 2015; Bay et al., 2017).

Challenges and Limitations

Despite their potential, genomic tools face several challenges. High costs, limited infrastructure, and the need for bioinformatics expertise can restrict their application, especially in developing regions. Data interpretation requires careful consideration to avoid misinformed management decisions. Ethical concerns related to genetic manipulation and data ownership also need to be addressed.

Future Perspectives

Conservation genomics is expected to playan increasingly important rolein predicting species responses to environmental change by integrating genomic data with ecological and climatic information. Emerging approaches such as pangenomics, multi-omics analyses, and machine learning will improve understanding of adaptive potential and population resilience, while tools like environmental DNA will support long-term and large-scale biodiversity monitoring (Allendorf et al., 2010; Ellegren, 2014). Ensuring ethical governance, interdisciplinary collaboration, and wider accessibility of genomic technologies will be essential for translating genomic insights into effective conservation policy and practice (Frankham et al., 2010).

Ethical Considerations

Genome technology, while offering powerful tools for conservation and biotechnology, raises important ethical concerns that must be carefully evaluated before real- world application. Key issues include potential ecological

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risks, long-term and unpredictable consequences, cost and accessibility, decision-making authority, and public acceptance. Interventions at the genomic level may permanently alter natural systems, making it essential to balance human intentions with environmental responsibility. Ethical implementation therefore requires transparent governance, scientific caution, and meaningful public engagement to ensure that such technologies are used responsibly and sustainably.

Conclusion

Genomic tools have transformed species conservation by providing detailed insights into genetic diversity, population dynamics, and adaptive potential. Their application enhances the effectiveness of conservation strategies, supports evidence-based decision- making, and strengthens efforts to preserve biodiversity in the face of global environmental change. As technologies continue to advance, genomics will play an increasingly central role in shaping sustainable conservation practices.

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Original Article

Integrative One Health Approaches in Disease Prevention

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Abstract

The One Health approach provides a holistic framework that integrates human, animal, and environmental health to prevent, detect, and respond to emerging infectious diseases. This paper reviews recent advances in One Health strategies, highlighting the role of artificial intelligence (AI), Internet of Things (IoT), genomic epidemiology, and integrated surveillance systems in disease prevention. A novel integrative framework is proposed that combines cross-sector collaboration, real-time data integration, predictive modeling, and IoT-enabled monitoring to enhance early warning and proactive intervention. The paper also addresses implementation challenges, including data interoperability, privacy concerns, and resource limitations, and presents recent case studies illustrating successful One Health initiatives. These insights aim to guide policymakers, researchers, and public health practitioners in developing sustainable, technology-enabled disease prevention strategies.

Keywords— *One Health, Disease Prevention, Integrated Surveillance, Artificial Intelligence, Internet of Things, Genomic Epidemiology, Predictive Modeling, Zoonotic Diseases.*

Introduction

Emerging infectious diseases pose a significant threat to global health, with over 60% originating from animal reservoirs. The traditional siloed approach to public health—where human, animal, and environmental health sectors operate independently—limits the effectiveness of early detection, prevention, and mitigation strategies. The One Health approach addresses this gap by promoting cross-sector collaboration, integrated surveillance, and a data-driven, technology-enabled framework for disease prevention.

Recent developments in AI, IoT, edge computing, and genomic epidemiology have created new opportunities to strengthen One Health initiatives. Integrating these technologies with traditional public health strategies can enhance predictive modeling, real-time monitoring, and rapid response mechanisms. This paper synthesizes current research, proposes an integrative framework, and highlights recent case studies demonstrating effective implementation.

II. Technological Enablers

A. Artificial Intelligence and Machine Learning

AI can process large, heterogeneous datasets from human health records, veterinary data, and environmental monitoring to predict disease outbreaks, track pathogen evolution, and optimize interventions. Machine learning models have been successfully applied to antimicrobial resistance prediction, zoonotic disease surveillance, and outbreak forecasting, enabling data-driven decision-making in real time.

B. Internet of Things (IoT) and Edge Computing

IoT devices, such as wearable animal sensors, vector monitoring traps, and environmental sensors, provide continuous, real-time data streams. When combined with edge computing, this data can be processed locally to reduce latency and enhance early detection, particularly in remote or resource-limited regions.

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C. Genomic Epidemiology

Genomic sequencing allows the identification of pathogen strains, mutations, and transmission chains. Integrating genomic data with clinical and environmental surveillance improves predictive accuracy and informs targeted interventions.

III. Proposed Integrative Framework

The proposed framework for integrative One Health disease prevention includes:

1. **Cross-Sector Governance** – Coordinated communication among public health, veterinary, environmental, and data science sectors.
2. **Integrated Surveillance Hub** – Centralized platform harmonizing clinical, veterinary, environmental, and genomic data.
3. **AI-Driven Predictive Models** – Machine learning for outbreak forecasting, antimicrobial resistance prediction, and early-warning alerts.
4. **IoT Edge Devices** – Distributed monitoring of vectors, livestock, and environmental conditions with local data processing.
5. **Feedback and Adaptation** – Continuous evaluation and iterative improvement of the system.

IV. Implementation Challenges

A. Data Interoperability

Integrating heterogeneous datasets across sectors requires standardization and adherence to FAIR (Findable, Accessible, Interoperable, Reusable) data principles.

B. Privacy and Ethical Concerns

Data sharing must comply with privacy laws and ethical standards. Federated learning and anonymization techniques can maintain privacy while allowing cross-sector collaboration.

C. Resource Limitations

Low- and middle-income countries may face challenges in adopting technology-driven solutions. International collaboration, capacity building, and funding support are critical to successful implementation.

Conclusion and Future Directions

Integrative One Health approaches represent a paradigm shift from reactive public health measures to proactive, predictive, and technology-driven disease prevention strategies. Incorporating AI, IoT, genomic epidemiology, and cross-sector governance can substantially improve resilience against emerging diseases.

Future work should focus on:

- Scaling integrated surveillance systems globally.
- Developing ethical and privacy-compliant data-sharing mechanisms.
- Enhancing community participation and policy adoption for sustainable implementation.

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Original Article

Oral Health within the one Health Paradigm: Bridging Human, Animal, and Environmental Health

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Abstract

The One Health paradigm recognizes the intrinsic interconnectedness of human, animal, and environmental health. While traditionally applied to zoonotic diseases, food safety, and antimicrobial resistance (AMR), its relevance to oral health remains underexplored. Oral diseases—particularly dental caries, periodontal disease, and oral cancers—are among the most prevalent non-communicable diseases globally and share risk factors with systemic illnesses. Furthermore, the oral microbiome acts as a dynamic interface between humans and their environment, influenced by ecological, behavioral, and socioeconomic determinants. This paper examines the integration of oral health into the One Health framework, emphasizing interdisciplinary collaboration, antimicrobial stewardship, environmental sustainability in dental practice, zoonotic considerations, and shared disease prevention strategies. Incorporating dentistry into One Health initiatives strengthens preventive health systems, enhances surveillance, and promotes sustainable health policies. The future of disease prevention demands inclusion of oral health as a core component of integrated global health strategies.

Introduction

Health systems have historically treated human, animal, and environmental health as distinct domains. However, emerging infectious diseases, climate change, biodiversity loss, and antimicrobial resistance have demonstrated the limitations of siloed approaches. The One Health concept, promoted by organizations such as the World Health Organization (WHO), Food and Agriculture Organization (FAO), and World Organisation for Animal Health (WOAH), calls for integrative, multisectoral collaboration.

Oral health is an essential yet often neglected component of global health. According to WHO estimates, oral diseases affect nearly 3.5 billion people worldwide. Dental caries, periodontal diseases, and oral cancers contribute significantly to morbidity, healthcare costs, and reduced quality of life. Importantly, oral conditions share biological pathways and behavioral risk factors with systemic diseases such as cardiovascular disease, diabetes mellitus, respiratory infections, and adverse pregnancy outcomes.

This paper argues that oral health should be explicitly integrated within the One Health paradigm to enhance disease prevention, strengthen surveillance systems, and promote sustainable healthcare delivery.

The One Health Framework: Principles and Scope

Conceptual Foundations

One Health is defined as an integrated approach aimed at achieving optimal health outcomes by recognizing the interconnection between people, animals, plants, and their shared environment. Core principles include:

Interdisciplinary collaboration, Shared surveillance and data exchange

Preventive and ecosystem-based approaches, Sustainable policy development

Originally rooted in comparative medicine, the concept evolved to address zoonotic diseases such as rabies and influenza. However, its application has expanded to chronic diseases, environmental toxicology, and antimicrobial resistance.

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Expanding One Health Beyond Zoonoses

Modern public health challenges—urbanization, climate change, industrial food systems, and global travel—require integrative prevention models. Oral health fits naturally within this expanded vision because:

- The oral cavity serves as an ecological interface.
- Oral microbiota interact with environmental exposures.
- Shared risk factors drive both oral and systemic diseases.

Oral Health as a Human–Animal–Environment Interface

The Oral Microbiome and Ecological Balance

The oral cavity hosts over 700 microbial species, forming a complex biofilm ecosystem. Health depends on microbial balance; dysbiosis leads to dental caries and periodontal disease.

Environmental influences on the oral microbiome include:

- Water fluoridation levels
- Air pollution
- Dietary patterns shaped by agricultural systems
- Exposure to heavy metals

Changes in environmental conditions can alter microbial diversity, influencing both oral and systemic inflammation.

Zoonotic and Cross-Species Considerations

1. Although oral diseases are largely non-communicable, zoonotic interactions are relevant:
2. Companion animals can harbor bacteria capable of infecting humans through bites or close contact.
3. Veterinary dentistry shares microbial and antibiotic stewardship concerns with human dentistry.
4. Livestock antibiotic use contributes to AMR patterns that affect human oral pathogens.
5. Cross-sector collaboration between dentists and veterinarians strengthens surveillance and stewardship.

Environmental Sustainability in Dental Practice

Dental practices contribute to environmental burden through:
Mercury-containing dental amalgam waste
Single-use plastics
Chemical disinfectants
High water consumption
Adoption of environmentally sustainable practices aligns dentistry with One Health goals. These include:
Amalgam separators
Eco-friendly sterilization systems
Reduced plastic use
Proper biomedical waste disposal
Sustainable dentistry reduces ecological impact and supports ecosystem health.

Shared Risk Factors and Integrated Disease Prevention

Common Risk Factor Approach (CRFA)

Oral diseases share risk factors with systemic non-communicable diseases (NCDs):
High sugar consumption
Tobacco use
Alcohol misuse
Poor hygiene practices
The CRFA promotes unified prevention strategies rather than disease-specific interventions.
For example:
Reducing sugar intake prevents dental caries, obesity, and diabetes.
Tobacco cessation lowers risk of oral cancer, lung disease, and cardiovascular disease.
Integration of oral health into NCD programs enhances efficiency and impact.

Oral-Systemic Health Connections

Periodontal inflammation contributes to systemic inflammatory burden. Evidence links periodontal disease to:
Atherosclerosis
Poor glycemic control in diabetes
Preterm birth
Respiratory infections
Dental clinics can serve as screening sites for systemic conditions, facilitating early detection and referral.

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Antimicrobial Resistance: A One Health Imperative

Antimicrobial resistance represents one of the most urgent global health threats. Dentistry contributes significantly to outpatient antibiotic prescribing.

A One Health approach to AMR in dentistry includes:

- Evidence-based prescribing guidelines
- Interprofessional collaboration with physicians and veterinarians
- Monitoring resistance patterns
- Public education on appropriate antibiotic use

Reducing unnecessary prescriptions in dental settings helps preserve antibiotic efficacy across sectors.

Surveillance and Public Health Integration

1. Dental settings offer untapped potential for disease surveillance:
2. Early detection of oral manifestations of systemic diseases
3. Monitoring nutritional deficiencies
4. Screening for tobacco and alcohol misuse
5. Identifying emerging infectious diseases with oral symptoms
6. Integrated health information systems can allow dental data to contribute to broader epidemiological monitoring.

Policy and Education Implications

Curriculum Reform

- Dental education should incorporate:
- One Health principles
- Environmental sustainability
- Public health and epidemiology
- Antimicrobial stewardship
- Interdisciplinary case discussions with medical and veterinary students can foster collaborative competencies.

Policy Development

- National health strategies should:
- Recognize oral health as part of universal health coverage
- Include dental metrics in One Health surveillance frameworks
- Support sustainable dental practice guidelines
- Policy inclusion ensures structural integration rather than symbolic alignment.

Challenges to Implementation

Barriers include:

- Professional silos between health disciplines
- Limited funding for preventive programs
- Inadequate data-sharing infrastructure
- Low public awareness of oral-systemic links
- Overcoming these requires leadership, advocacy, and cross-sector partnerships.

Future Directions

Future research should explore:

- Microbiome-environment interactions
- Climate change effects on oral health
- Cost-effectiveness of integrated prevention models
- Digital health platforms linking dental and medical data
- Artificial Intelligence May Enhance Predictive Modeling Of Disease Risk Using Integrated Datasets.

Conclusion

Oral health occupies a critical yet under recognized position within the One Health paradigm. The oral cavity functions as an ecological interface influenced by environmental conditions, human behavior, and microbial dynamics. Integrating dentistry into One Health initiatives strengthens disease prevention, enhances antimicrobial stewardship, supports environmental sustainability, and promotes systemic health monitoring.

A comprehensive One Health strategy must therefore transcend traditional disciplinary boundaries and fully incorporate oral health as a foundational pillar of global health systems. Bridging human, animal, and environmental health through dentistry is not merely an academic proposition—it is a practical necessity for sustainable disease prevention in the twenty-first century.

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Original Article

Evaluation of Sulphate in Relation to TSS, TDS, Turbidity and Conductivity in Nandan Pahar Pond, Deoghar, Jharkhand, India

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Abstract

Sulphate plays a significant role in freshwater hydrochemistry and can influence ionic strength, conductivity, and suspended particulate matter. The present study evaluates quarterly sulphate dynamics in relation to Total Suspended Solids (TSS), Total Dissolved Solids (TDS), turbidity, and electrical conductivity in Nandan Pahar Pond, Deoghar, Jharkhand, from July 2024 to April 2025. Observed sulphate concentrations ranged from 9.897 mg/L to 19.44 mg/L, with the highest values recorded in July (19.44 mg/L) ***and*** *the lowest in January (9.897 mg/L). TDS values varied from 152 mg/L to 260 mg/L, conductivity from 242.2 µS/cm to 401.7 µS/cm, and TSS remained consistently low (<1–4.3 mg/L), indicating limited particulate pollution. Seasonal trends revealed that sulphate exhibited a positive association with conductivity and TDS, suggesting ionic enrichment during dry and post-monsoon periods. The findings highlight stable water quality conditions, low pollution stress, and the ecological sustainability of the pond, while emphasizing the importance of continuous monitoring for long-term conservation.*

Keywords: *Sulphate, Electrical Conductivity, TDS, TSS, Turbidity, Seasonal Variation, Limnology, Nandan Pahar Pond, Water Quality*

Introduction

Freshwater ecosystems are highly sensitive to chemical fluctuations that influence biological productivity, ecosystem stability, and water usability. Among inorganic anions, sulphate (SO_4^{2-}) serves as an important indicator of geochemical weathering, anthropogenic runoff, and ionic balance. Its concentration often correlates with dissolved solids, conductivity, and turbidity, thereby reflecting overall hydrochemical conditions. Limnology can be defined as interrelationships of organisms of inland waters as they are affected by their dynamic physical, chemical, and biotic environments (Wetzel, 2001).

Ponds in semi-urban and pilgrimage regions, such as Nandan Pahar Pond in Deoghar, Jharkhand, are increasingly subjected to seasonal hydrological changes, surface runoff, and anthropogenic pressures. Understanding sulphate dynamics in relation to TSS, TDS, turbidity, and electrical conductivity is essential for assessing water sustainability, ecosystem health, and pollution resilience.

This study aims to:

Analyze quarterly sulphate fluctuations

Examine relationships with TSS, TDS, turbidity, and conductivity

Evaluate seasonal impacts on water quality

Provide baseline data for sustainable water management

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Study Area

Nandan Pahar Pond is located in Deoghar district, Jharkhand, India**,** a region influenced by monsoonal rainfall, tourism activity, and seasonal water recharge**.** The pond supports local biodiversity, recreational use, and groundwater recharge**,** making its ecological health significant. Sharma et al., 2025, had done vast research on the Heavy metals of Nandan pahar Pond, Deoghar.

Fig 1: Google Map view of Nandan pahar Pond Deoghar Jharkhand India

Materials and Methods

Analytical Methods

Standard procedures recommended by **APHA (2017)** were followed. Research was conducted at CSIR Institute, Durgapur (Recognized By West Bengal Pollution Control Board).

Table-1: Process of measurement of various physicochemical parameters:

Sl No	**Parameters**	**Method follow (APHA, 2017, 23RD Edition**
1	Turbidity (NTU)	2130-B: Turbidity Determination By Nephelometric Method
2	Conductivity S/cm	2510-B: Conductivity Determination By Laboratory Method
3	TDS (mg/L)	2540-C: Total Dissolved Solids (TDS) By Total Dissolved Solids Dried at 180^0C Method
4	TSS (mg/L)	2510-D: Total Suspended Solids (TSS) By Total Suspended Solids Dried at 103 – 105^0C Method
5.	Sulphate (mg/L)	4500-SO_4^2 E: Solfate Determination By Turbidimetric Method

Results

Quarterly Data Summary (Nandan Pahar Pond)

Quarterly monitoring of sulphate, Total Suspended Solids (TSS), Total Dissolved Solids (TDS), turbidity, and electrical conductivity in Nandan Pahar Pond from July 2024 to April 2025 revealed notable seasonal fluctuations influenced by hydrological and environmental factors.

Sulphate concentration ranged from 9.897 mg/L (January 2025) to 19.44 mg/L (July 2024)**,** with elevated levels during the monsoon season likely due to surface runoff and mineral leaching. A decline during winter months suggests reduced external inflow and improved dilution conditions.

Total Dissolved Solids (TDS) varied between 152 mg/L (October 2024) and 260 mg/L (April 2025)**,** showing an increasing trend toward summer, potentially due to evaporation, concentration of dissolved ions, and reduced water volume.

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Electrical conductivity followed a similar seasonal pattern, ranging from **242.2 µS/cm (October 2024)** to **401.7 µS/cm (April 2025)**, reflecting the ionic composition and dissolved mineral load of the pond water.
Turbidity values remained relatively low throughout the study period, fluctuating between **0.5 NTU (January 2025)** and **1.4 NTU (July 2024).** Higher turbidity during the monsoon indicates sediment inflow and suspended particulate matter.
Total Suspended Solids (TSS) recorded **4.3 mg/L in July 2024,** while remaining **below detection limits (<1 mg/L)** in subsequent quarters, indicating limited particulate suspension outside the rainy season.
Overall, the results highlight a **strong interrelationship between sulphate, dissolved solids, turbidity, and conductivity**, suggesting that **seasonal runoff, evaporation, and catchment influences** play a key role in determining water quality dynamics in Nandan Pahar Pond.

Table 2: Quarterly Variation of Key Physico-Chemical Parameters in Nandan Pahar Pond

Parameter	Unit	July 2024	October 2024	January 2025	April 2025
Sulphate	mg/L	19.44	12.146	9.897	13.797
TDS	mg/L	160	152	170	260
TSS	mg/L	4.3	<1	<1	<1
Turbidity	NTU	1.4	0.6	0.5	0.8
Conductivity	µS/cm	262	242.2	270	401.7

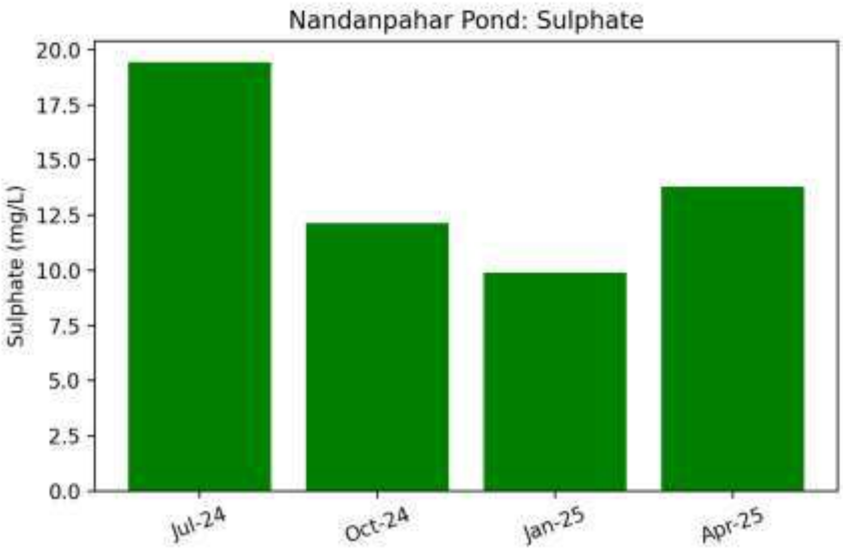

Fig 2- Quarterly variation of Sulphate in Nandan pahar pond Deoghar Jharkhand

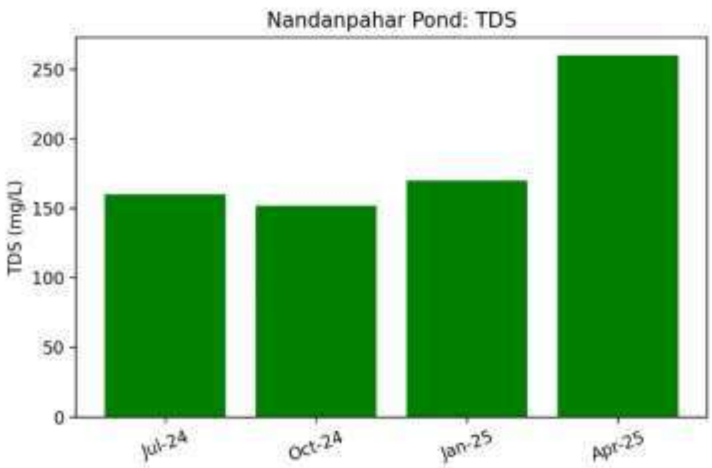

Fig 3- Quarterly variation of TDS in Nandanpahar Pond , Deoghar Jharkhand India

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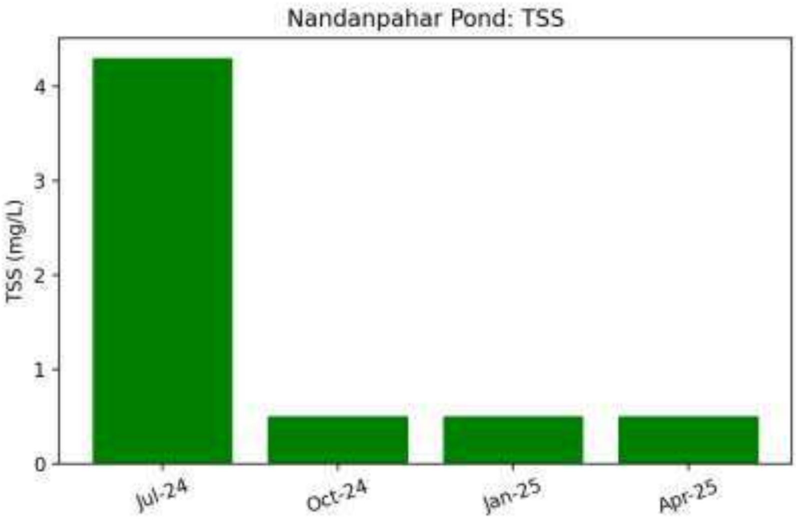
Fig 4- Quarterly variation of TSS in Nandan pahar pond Deoghar Jharkhand



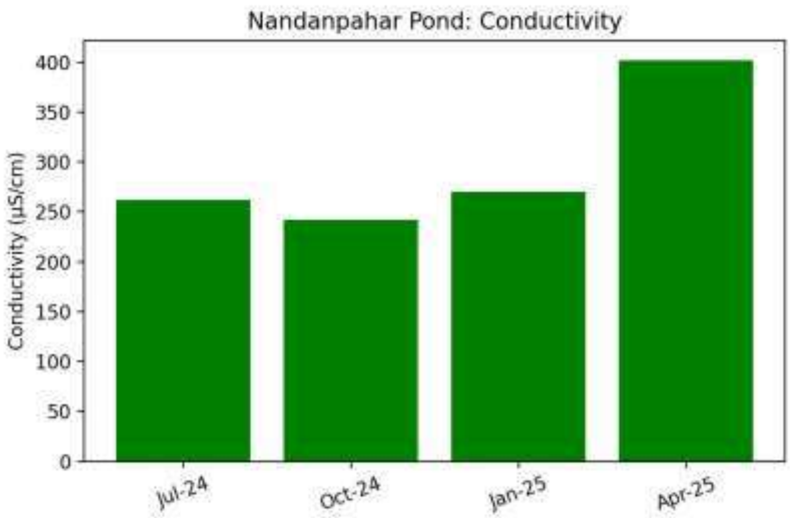


Fig 5 – Quarterly variation of Conductivity in Nandan pahar pond , Deoghar Jharkhand

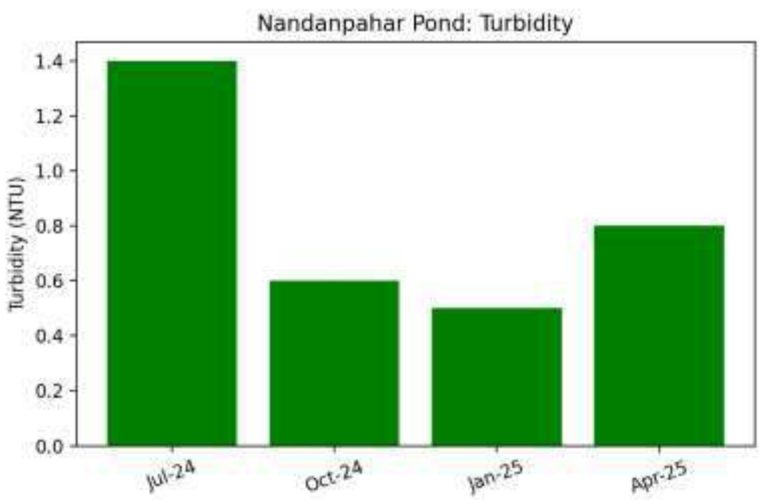


Fig 6- Quarterly variation of Turbidity in Nandan pahar pond Deoghar Jharkhand

Discussion

Seasonal Variation of Sulphate

Sulphate peaked in monsoon (July) due to surface runoff, mineral dissolution, and soil leaching, while the lowest concentration in winter (January) reflected reduced inflow and sediment input. Sulphate may be present in waterbodies due to bathing and washing of clothes (Jain et al. 1996).

Relationship with TDS and Conductivity

Sulphate exhibited a positive relationship with TDS and conductivity**,** indicating its role in enhancing ionic strength and dissolved mineral load, especially during summer evaporation periods**.** Tripathy & Pandey (1990) reported maximum concentration of TDS and TSS during summer. It may be due to low water flow into the waterbodies and high evaporation rate. The differences in conductivity could be caused by the soil types, farming methods, and geological factors in the study location, Duressa et. al., (2019).

Association with TSS and Turbidity

The low TSS (<1–4.3 mg/L) suggests minimal particulate contamination, explaining the moderate and stable sulphate levels. This indicates that sulphate presence is largely dissolved rather than particle-bound. TSS makes a body of water more turbid, which reduces light penetration and hinders aquatic plants' ability to photosynthesize, potentially resulting in oxygen deficiency, Butler and Ford (2018).

Ecological and Water Quality Implications

All recorded sulphate concentrations were **well within WHO and BIS permissible limits**, indicating **low pollution risk**. Stable turbidity and suspended solids levels further support the pond's **good ecological health and resilience**.

Environmental Significance

The study highlights: Low anthropogenic contamination, Stable ionic balance, Sustainable hydrochemical conditions and Strong potential for biodiversity conservation and long-term water sustainability.

Conclusion

Sulphate levels in Nandan Pahar Pond show moderate seasonal fluctuation with strong associations with TDS and electrical conductivity. Low TSS and turbidity values confirm minimal pollution **stress** and favorable ecological conditions. Continuous monitoring is recommended to prevent future degradation and to strengthen water conservation strategies**.**

Recommendations

Long-term monitoring of ionic parameters, Control of runoff and sediment inflow, Public awareness on sustainable pond usage and Integration into **local water conservation policies.**

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Original Article

Exploring the Variability in Water Quality Around Nipani: A Detailed Analysis of DO, CO_2, Hardness and pH

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Abstract
Water quality assessment is essential for determining the suitability of water for domestic, agricultural, and ecological purposes. The present study evaluates the variability of four important physico-chemical parameters—pH, Dissolved Oxygen (DO), Dissolved Carbon Dioxide (CO_2), and Hardness—in fourteen water samples collected from ponds, rivers, wells, borewells, tanks, and tap water sources across Nipani and nearby regions. The results show noticeable spatial variation in DO, CO_2, and hardness, while pH remained mostly neutral. Surface flowing waters showed comparatively higher DO levels, whereas borewell and stagnant water sources exhibited lower oxygen content. Hardness values were within moderate limits but varied depending on geological conditions. The findings provide baseline data for future monitoring and water resource management in the region.
Keywords: *Physico-chemical Parameters; pH, Dissolved Oxygen (DO), Dissolved Carbon Dioxide (CO_2), Total Hardness, Spatial Variability, Water Resource Management.*

Introduction

Water is a fundamental natural resource necessary for human survival and ecosystem balance. Its quality is determined by physical, chemical, and biological characteristics. Among various parameters, pH, Dissolved Oxygen (DO), Dissolved Carbon Dioxide (CO_2), and Total Hardness are crucial indicators of water health.

- **pH** indicates acidity or alkalinity.
- **Dissolved Oxygen (DO)** reflects the oxygen available for aquatic organisms.
- **Carbon Dioxide (CO_2)** influences acidity and biological activity.
- **Hardness** represents calcium and magnesium salt concentrations.

Nipani and surrounding areas rely on multiple water sources such as the Hiranyakeshi River, Dudhganga River, Vedganga River, ponds, wells, borewells, and municipal supplies. Assessing these parameters helps determine their suitability for drinking and ecological sustainability.

Objectives

1. To determine pH, DO, CO_2, and hardness of selected water samples.
2. To compare variability among different water sources.
3. To evaluate water suitability for domestic and environmental use.

Materials and Methods

Fourteen water samples were collected from:

- Pond water (Hebbal, GIB Nipani)
- Hiranyakeshi River (Hebbal)
- Dudhganga River (Karadaga)
- Vedganga River (Yamgarni and Mamdapur)
- Appachiwadi lake and tank

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- Borewell and filtered borewell water (Nipani)
- Tap water (Nipani)
- Wells (Nipani)

Samples were collected in clean, airtight bottles and analyzed within 24 hours.

Analytical Methods

Parameter	Method Used
pH	pH strip method
Dissolved Oxygen	Winkler's titration method
Dissolved CO_2	Titrimetric method
Hardness	EDTA titration method

Results

Observed Data

Sample	pH	DO (mg/L)	CO_2 (mg/L)	Hardness (mg/L)
Hiranyakeshi River, Sankeshwar	7	2.27	6.6	54
Dudhganga River, Karadaga	7	9.96	4.4	54
Vedganga River, Yamgarni	7	4.55	8.8	50
Vedganga River, Mamdapur	7	4.84	8.8	66
Pond, Hebbal	7	5.42	19.8	48
Pond, GIB campus Nipani	7	1.42	6.6	40
Appachiwadi Lake	7	1.42	6.6	42
Appachiwadi Tank	6.5	5.12	8.8	44
Ashirwad Bhavan Well	7	6.26	11	62
Well Mahadevgalli, Nipani	7	3.98	6.6	48
Filtered Borewell Mahadevgalli, Nipani	7	8.54	4.4	68
Borewell Mahadevgalli, Nipani	7	0.85	6.6	52
Borewell GIBC, Nipani	7	1.99	7.2	72
Tap water GIBC, Nipani	7	9.39	15.4	62

Discussion

pH Analysis

Most samples showed neutral pH (7), indicating balanced acidity and alkalinity. Only Appachiwadi tank water showed slightly acidic tendency (6.5), but still within acceptable drinking limits (6.5–8.5).

Dissolved Oxygen (DO)

- Highest DO: Dudhganga River (9.96 mg/L)
- Lowest DO: Borewell water (0.85 mg/L)

Flowing rivers like the Dudhganga showed high oxygenation due to turbulence. Borewell and stagnant pond waters showed low DO, possibly due to limited aeration and higher microbial activity.

Dissolved CO_2

- Highest CO_2: Pond, Hebbal (19.8 mg/L)
- Lowest CO_2: Dudhganga River and Filtered Borewell (4.4 mg/L)

High CO_2 in ponds suggests decomposition of organic matter. Lower CO_2 in rivers indicates better aeration.

Hardness

Hardness ranged from 40 mg/L to 72 mg/L.

- Highest hardness: Borewell (72 mg/L)
- Lowest hardness: Pond, GIB (40 mg/L)

All samples fall under moderately hard water category but are within permissible drinking limits.

Comparative Interpretation

- Flowing rivers generally showed higher DO and lower CO_2.
- Borewell waters showed lower DO and higher hardness.
- Tap and filtered borewell water showed improved oxygen content.
- Hardness variation reflects geological mineral composition.

Conclusion

The study demonstrates significant variability in water quality parameters across Nipani and nearby regions. Surface flowing waters such as the Dudhganga River exhibited better oxygenation, while borewell and stagnant sources

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showed lower DO levels. CO_2 concentration was higher in ponds, indicating biological activity. Hardness remained within moderate and permissible limits across all samples. Overall, most water sources are chemically acceptable, but low DO in certain sources suggests the need for monitoring.

Recommendations

1. Regular monitoring of borewell and stagnant water sources.
2. Proper maintenance of ponds and tanks to prevent organic accumulation.
3. Periodic water testing before domestic consumption.
4. Further study including microbial and heavy metal analysis.

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Original Article

Effect of Enriched Biofertilizer of Sugarcane Pressmud on Growth of Brinjal (*Solanum melongena L.)* under Laboratory Conditions

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Abstract

Sugarcane pressmud is a major by-product of the sugar industry and its disposal poses environmental challenges. The present study evaluates the effect of enriched biofertilizer prepared from sugarcane pressmud on growth, yield, biochemical parameters of brinjal and soil fertility under pot culture conditions. Four treatments were tested: control (T1), composted pressmud (T2), enriched composted pressmud (T3), and enriched composted pressmud with fruit waste (T4). Results showed that enriched pressmud significantly improved plant growth, yield attributes, chlorophyll and polyphenol content, and soil physico-chemical properties. The study demonstrates that enriched pressmud biofertilizer can serve as an effective and eco-friendly alternative to chemical fertilizers.
Keywords: *Pressmud, Biofertilizer, Brinjal, Soil fertility, Microbial inoculants*

Introduction

Sugarcane is one of the most important commercial crops cultivated in tropical and subtropical regions of the world. India is among the leading producers of sugarcane, and the sugar industry plays a crucial role in the country's agro-based economy by providing employment opportunities and supporting rural livelihoods (Yadav & Solomon, 2006). However, large-scale sugar production generates substantial quantities of by-products such as bagasse, molasses, and pressmud. Among these, pressmud is produced at the rate of approximately 3–4% per tonne of sugarcane crushed, creating significant disposal and environmental management challenges (Patil & Shingate, 1981; Kalaivanan & Hattab, 2008).

Pressmud is a soft, spongy, dark brown residue obtained during the clarification of sugarcane juice using lime and sulphur dioxide. It is rich in organic matter, macronutrients such as nitrogen, phosphorus, potassium, calcium, and magnesium, as well as micronutrients like iron, zinc, manganese, and copper (Bangar et al., 2000; Yadav & Solomon, 2006). Due to its high organic carbon content and water-holding capacity, pressmud has considerable potential for improving soil physical, chemical, and biological properties when applied to agricultural soils (Dotaniya & Datta, 2014).

In recent years, the excessive use of chemical fertilizers has led to declining soil fertility, nutrient imbalance, environmental pollution, and reduced crop productivity. Sustainable agriculture emphasizes the recycling of organic wastes and the use of biofertilizers to maintain soil health and crop yield (Sharma et al., 2002). Enrichment of pressmud with beneficial microorganisms such as nitrogen-fixing bacteria and phosphate-solubilizing microorganisms enhances nutrient availability, accelerates decomposition, and improves its efficiency as a biofertilizer (Patil et al., 2013; Dotaniya et al., 2013).

Brinjal (*Solanum melongena* L.) is one of the most widely cultivated vegetable crops in India and is valued for its nutritional and economic importance. Brinjal is highly responsive to soil fertility and nutrient management practices (Bhosale et al., 2012).

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The integration of enriched organic amendments like pressmud into brinjal cultivation can improve growth, yield, and quality while reducing dependence on chemical fertilizers (Patil et al., 2013).

The present study was undertaken to evaluate the effect of enriched sugarcane pressmud biofertilizer on the growth, yield, biochemical characteristics of brinjal, and soil physico-chemical properties under controlled pot culture conditions. The study also aims to assess the potential of enriched pressmud as an eco-friendly and sustainable nutrient source for vegetable production (Dotaniya & Datta, 2014; Yadav & Solomon, 2006).

Materials and Methods (with in-text references)

1 Collection and Processing of Pressmud

Sugarcane pressmud was collected from Shri Shahu Sahakari Sakhar Karkhana Ltd., Kagal, Kolhapur district, Maharashtra. The freshly collected pressmud was air-dried under shade to remove excess moisture and then composted to stabilize organic matter and reduce phytotoxicity (Patil & Shingate, 1981; Kalaivanan & Hattab, 2008). The composted material was sieved to obtain uniform particle size and stored for further enrichment (Yadav & Solomon, 2006).

2. Isolation and Mass Multiplication of Microorganisms

Indigenous nitrogen-fixing and phosphate-solubilizing microorganisms were isolated from pressmud samples using standard serial dilution and plating techniques (Wollum, 1982). Nitrogen-fixing bacteria were isolated on Ashby's nitrogen-free medium, while phosphate-solubilizing microorganisms were isolated on Pikovskaya's agar medium (Pikovskaya, 1948; Subba Rao, 1999). Efficient isolates showing maximum growth and nutrient solubilization were selected for mass multiplication.

Selected microbial cultures were grown in sterile nutrient broth and incubated at room temperature on a rotary shaker at 70–80 rpm for 36–40 hours (Somasegaran & Hoben, 1994). The actively growing cultures were centrifuged to obtain microbial biomass, which was used for enrichment of pressmud.

3 Preparation of Enriched Pressmud Biofertilizer

The composted pressmud was sterilized and thoroughly mixed with microbial biomass to obtain an approximate population density of 10^5 colony-forming units per gram of carrier material, following standard biofertilizer preparation techniques (Subba Rao, 1999; Patil et al., 2013). The enriched pressmud was cured for stabilization and stored under ambient conditions until use.

4 Experimental Design and Crop Management

A pot culture experiment was conducted during the rabi season using healthy and uniform brinjal seedlings. Pots were filled with well-mixed soil and treatments were applied as follows:

T1: Control (no amendment)
T2: Composted pressmud
T3: Enriched composted pressmud
T4: Enriched composted pressmud with fruit waste

All treatments were replicated and arranged in a completely randomized design (CRD) (Gomez & Gomez, 1984). Uniform irrigation, weeding, and plant protection measures were followed throughout the experimental period.

5 Growth, Yield, and Biochemical Analysis

Plant height, number of leaves, branches, flowers, and fruits were recorded at 30-day intervals up to 150 days after planting following standard agronomic procedures (Panse & Sukhatme, 1985). Leaf chlorophyll content was estimated using standard spectrophotometric methods (Arnon, 1949). Polyphenol content was determined to assess plant metabolic and defense responses using established biochemical methods (Sadasivam & Manickam, 1996).

6 Soil Analysis

Soil samples were collected before planting and after harvesting. Parameters such as pH, organic carbon, organic matter, available nitrogen, phosphorus, potassium, and water-holding capacity were analyzed using standard laboratory procedures (Jackson, 1973; Allison, 1965).

7 Statistical Analysis

Experimental data were subjected to statistical analysis to evaluate treatment effects and determine significant differences among treatments using appropriate statistical methods (Gomez & Gomez, 1984).

Results and Discussion

1 Effect of Enriched Pressmud on Plant Height

Plant height increased progressively with crop age in all treatments; however, the magnitude of increase varied significantly among treatments. Enriched composted pressmud (T3) consistently recorded the highest plant height at all growth stages. At 150 days after planting, T3 recorded a maximum plant height of 53.54 cm, followed by T4 (48.94 cm) and T2 (48.44 cm), while the control recorded the lowest height (42.14 cm).

The enhanced plant height under T3 treatment may be attributed to improved availability of essential nutrients, particularly nitrogen and phosphorus, due to microbial activity. Nitrogen-fixing bacteria contribute to continuous nitrogen supply, while phosphate-solubilizing microorganisms increase phosphorus availability, promoting cell division and elongation. Similar improvements in plant height due to pressmud application have been reported earlier.

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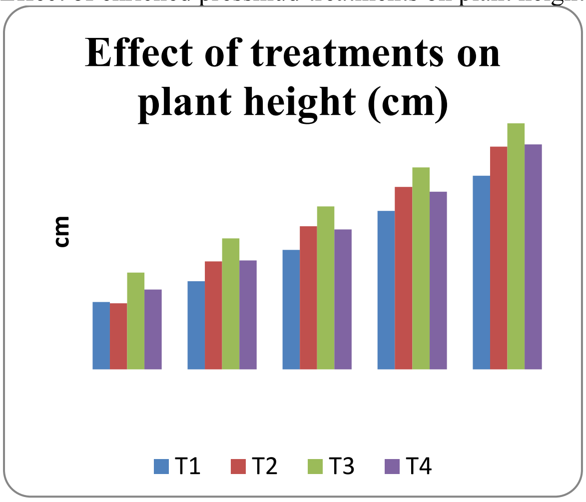
Table 1. Effect of treatments on plant height (cm)

Treatment	30 days	60 days	90 days	120 days	150 days
T1	14.68	19.20	26.00	34.50	42.14
T2	14.40	23.48	31.10	39.66	48.44
T3	21.06	28.52	35.46	43.92	53.54
T4	17.36	23.68	30.42	38.66	48.94

Figure 1. Effect of enriched pressmud treatments on plant height of brinjal.



2 Effect on Leaf Production and Branching

The number of leaves and branches per plant increased with plant age in all treatments. Enriched pressmud (T3) and enriched pressmud with fruit waste (T4) showed significantly higher leaf numbers compared to control. Increased leaf production enhances photosynthetic capacity, leading to higher biomass accumulation.

Branch formation followed a similar trend, with T3 recording the highest number of branches at later growth stages. Enhanced branching is indicative of improved vegetative vigor and nutrient uptake, resulting from improved soil fertility and microbial activity.

3. Effect on Flowering and Fruiting

Flower initiation and fruit development were positively influenced by enriched pressmud application. T3 recorded the highest number of flowers and fruits per plant at harvest. Balanced nutrient supply and improved physiological processes under enriched treatments contributed to enhanced reproductive growth.

Table 2. Effect of treatments on fruits per plant (150 days)

Treatment	Fruits per plant
T1	1.8
T2	2.2
T3	2.4
T4	1.4

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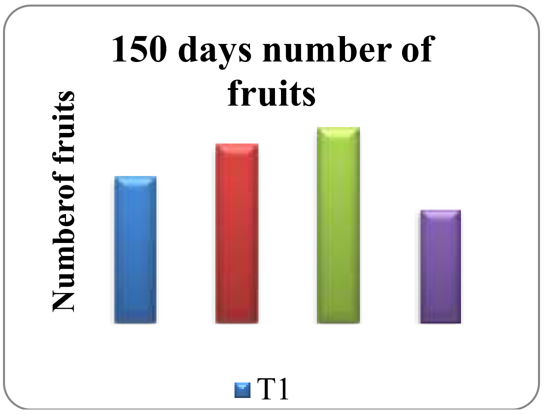
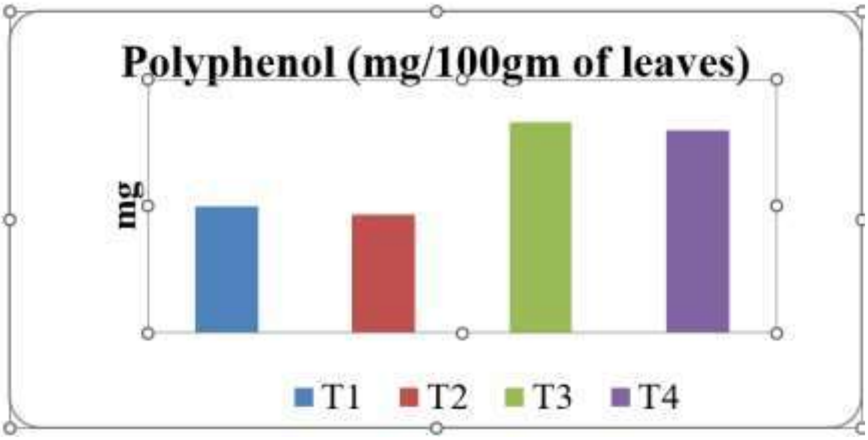
Figure 2. Effect of enriched pressmud on fruit yield of brinjal.





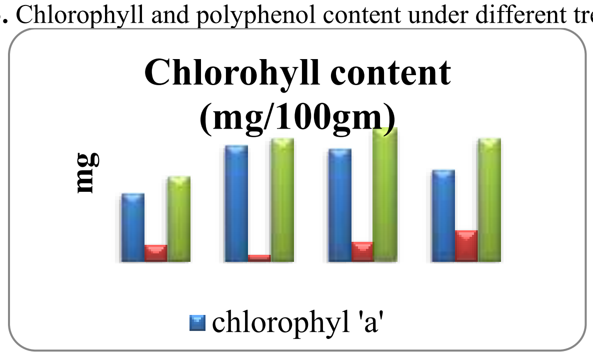
4 Biochemical Parameters

Total chlorophyll content was highest in T3, indicating enhanced photosynthetic efficiency due to improved nitrogen availability. Polyphenol content was also significantly higher in enriched treatments, suggesting improved metabolic activity and plant defense mechanisms.

Table 3. Biochemical parameters of brinjal leaves

Treatment	Total Chlorophyll (mg/100 g)	Polyphenol (mg/100 g)
T1	9.74	6000
T2	14.07	5600
T3	15.12	10000
T4	14.09	9600

Figure 3. Chlorophyll and polyphenol content under different treatments.



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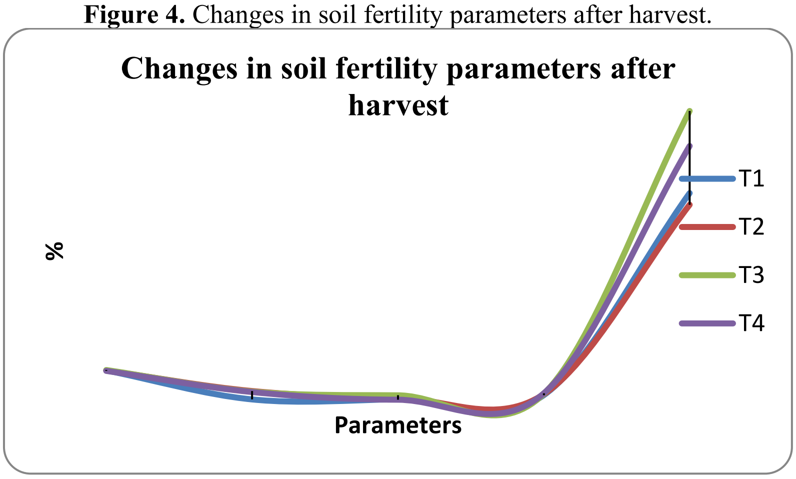
5 Soil Physico-Chemical Properties

Application of enriched pressmud significantly improved soil organic carbon, nitrogen, phosphorus, potassium, and water-holding capacity. Soil pH remained near neutral, indicating the safe use of pressmud without adverse effects. Improved soil structure and moisture retention under enriched treatments contributed to better plant growth and yield.

Table 4. Post-harvest soil properties

Parameter	T1	T2	T3	T4
pH	7.2	7.2	7.3	7.1
Organic carbon (%)	0.45	2.40	2.27	2.17
Nitrogen (%)	0.49	0.84	1.41	0.38
Phosphorus (%)	1.45	1.67	1.76	1.88
Water holding capacity (%)	48.51	45.80	67.64	59.48

Figure 4. Changes in soil fertility parameters after harvest.



Conclusion

The study concludes that enriched composted pressmud significantly enhances growth, yield, biochemical properties of brinjal, and improves soil fertility. Enrichment with nitrogen-fixing and phosphate-solubilizing microorganisms plays a key role in nutrient mobilization and plant growth promotion. The use of enriched pressmud biofertilizer offers a sustainable, eco-friendly alternative to chemical fertilizers while simultaneously addressing pressmud disposal problems of the sugar industry.

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Original Article

Soil analysis of different villages of Nipani Tehsil, Belgavi, Karnataka

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Abstract

Soil is a complex combination of organic matter, gases, minerals, organisms, and liquids that support life. The pedosphere, or the Earth's body of soil, has four important functions: it is a medium for plant growth, it stores water, supplies and purifies, it modifies the Earth's atmosphere, and it is a habitat for organisms. Soil is one of the principal substrata of life on Earth, which participates in the cycling of carbon and other elements through the global ecosystem.

Soil is a very important factor from an agricultural point of view. As pollution is ever rising in the world, soil is losing its quality owing to the unregulated dumping of debris, which leads to the formation of toxic sediments.

This project involves testing soil samples for basic parameters such as pH, conductivity, and moisture content.

- pH determines whether the soil sample is acidic or basic.
- The specific conductance of the soil sample is a measure of the amount of soluble salts present in the soil sample.
- Moisture content is the quantity of water present in a soil sample.

In this project, two soil samples were tested.
1)Black Soil.
2)Red Soil.

Soil is a complex of various organic matter, gasses, minerals, organisms and liquids all of which support our life. The earth's body of soil is known as the pedosphere, which has four important functions.

Soil is used for the growth of plants, helps to store water, is said to be the modifier of the earth's atmosphere, and is a habitat for organisms.

- The color of the soil indicates its history as well as the compounds present in the soil.
- White or gray soil may contain lime or may have been leached (all water removed).
- Black or gray soil indicates that the soil contains organic materials and moisture.
- Red, brown, or yellow soil usually indicates the presence of iron compounds.

Definition of soil.

Soil can be defined as the organic and inorganic material on the surface of the earth that providesa medium for plant growth.

Types of soil:

- Sandy soil - Made up of large particles, it drains quickly and is easy to work with.
- Silt soil -Has smaller particles than sand, is smooth to the touch, and can hold water better than sandy soil.
- Clay soil contains the smallest particles, holds water well, but may not drain as quickly as other types.

Loamy soil is a mixture of sand and silt clay, making it well-draining and fertile.

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Soil Profile:

A soil Profile is defined as the vertical section of the soil from the ground surface downwards, where the soil meets the underlying rock.

Nutrients present in soil

Nitrogen, sodium, potassium, calcium, iron, magnesium, sulfur,carbon, and

Materials:

Beaker, funnel, water, pH meter
The major steps in practical soil testing are
1) Soil follows:
2)Preparation of soil sample.
3)Extraction or analysis of available nutrients by an appropriate laboratory method.

Soil analysis is a set of various chemical process that determine the amount of available plant nutrients in the soil, but also the chemical, physical and biological soil properties important for plant nutrition. Chemical soil analysis determines the content of plant nutrients, nitrogen (N), phosphorus, potassium, pH, humuscontent, totalCaCO, available lime organic matter, total sulphur (S), sodium, micro nutrients and other physical characteristics
(capacity, permeability, density, pH value).

pH of soil

The chemical property of the soil depends upon the presence of different types of nutrients and pH of the soil. The soil pH is important in determining the availability of soil minerals. Different plants have different optimum soil pH requirements.

Procedure for pH of the soil sample

- Take the collected red soil and black soil into two different beakers containing water.
- Take the soil sample into the beaker and add distilled water into the beaker.
- Then keep the soil sample or soil solution beside for 10 minutes.
- Then take the soil sample and filter it.and check the pH of soil with the help of pH meter.

How to use EC and TDS meter:

To use a T DS and EC meter for soil you'll need to collect a soil sample, prepare it with distilled water, and then measure the EC or TDS of the solution using the meter.

You'll first need to prepare a soil sample.Collect soil sample from different depths and location within the area you want to test then mix them thoroughly for an EC (Electrical conductivity) measurement,you'll typically create a soil slurry by mixing the soil with distilled water, stirring and then measuring the EC of the solution.For TDS (Total Dissolved Solids), you can either use a meter directly inserted into the soil or prepare a soil solution as for EC and measure the TDS of that.

Procedure for EC and TDS Collect soil sample-

Collect soil sample from different depths and location within the area you want to test ,mix these samples thoroughly to create a representative sample.
Preparation of soil sample -

- Add distilled water to the soil sample in a specific ratio.

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- Stir the mixture thoroughly for about 30 seconds.
- Let the mixture settle for about 1 5 minutes.
- Filter the liquid through a clean breaker to remove solid particles.

Measure EC and TDS EC meter:

- Insert the EC probe (sensor) into the filtered liquid.
- Wait for the reading to stabilize.
- Read the EC value from the meter, typically in ds/m(decisions per meter)or similar units.

TDS (Total Dissolved Solids) in Soil Sample.

Total dissolved solids refers to the measure of all inorganic and organic substances dissolved in water, including minerals, salts and organic matter.

TDS quantified the total amount of solids dissolved in water, excluding the water molecule themselves. These solids can be in the form of molecules. ions or tiny particles.

Measurement:

- T DS is typically measured in parts per million (ppm) or miligrams per liter(mg/L).
- T DS is a crucial factor in hydroponic system where nutrient solution are used to grow plants.
- Monitoring TDS helps ensure the right balance of nutrients.

Soil Testing

T DS can be used to assess the overall quality of soil water.

1)Sample preparation:

collect a representative soil sample and mix it with distilled or deionized water in a specified ratio.

2)Extraction

Allow the mixture to settle and shake periodically. Then filter the solution to remove any large particles.

Take the soil sample in clean beaker.

Dip the T DS meter probe into the soil sample wait for the reading to stabilize.

Note the T DS value (in parts per million.ppm)

Soil organic carbon:

Soil organic carbon is a measureable component of soil organic matter.

Procedure for soil organic carbon:

- Take a small spoon of soil sample in a beaker or soil mixing bottle.

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- Then add 5 ml of soil organic carbon detection kit solution A and 5 ml of soil organic carbon detection kit solution B in a beaker or soil mixing bottle.
- The keep the soil sample beside for 5 minutes.
- And check the soil colour with the help of colour chart for soil organic carbon by tech source solutions.
- Then note down the value for organic carbon.


Result:

Sl. No.	Sample	pH	TDS	EC	Potassium	Medium
1.	Black soil	8.1	0.179 ppm	0358 gs/cm	K=79.3 ppm	1%
2.	Red soil	8.0	0.16 ppm	0.322 ps/crn	K=4.8 ppm	1%
3	Road side soil	7.7	0.195 ppm	0.390 gs/cm	K=60.8 ppm	0.5-1%
4.	Silt soil	7.8	0.179 ppm	0.358 gs/cm	K=11.9 ppm	Sufficient

Observation:

When the um-versal pH indlcator is added to the beaker containing the soil solution, the colour changes. These colour changes can be tracked using the pH colour chart.

The Red soll has a pH level of S.0 while Black soil has a pH level of 8.1. It IS basic_ The Road Side soil has a pH level of 7.7

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Original Article

Volatile Organic Compounds as Medical Clues: The Role of Bio-Sniffers- A review

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Abstract

Bio-sniffers are an innovative technology with immense potential in medical diagnostics. They detect volatile organic compounds (VOCs) in exhaled breath to evaluate disease conditions and metabolic health. These devices stand out for their rapid, sensitive, and portable capabilities, distinguishing them from traditional methods like gas chromatography-mass spectrometry (GC-MS) and gas chromatography time-of-flight mass spectrometry (GC-TOF-MS).
This review explores the metabolic pathways and detection mechanisms of VOCs in the human body, emphasizing their roles as biomarkers for various diseases. It highlights the detection principles, performance attributes, and medical applications of two primary types of bio-sniffers: electrical sensors and optical sensors. Furthermore, the review addresses the current challenges in VOC monitoring, discusses future development prospects, and offers strategies for improving detection sensitivity and minimizing environmental interference.

Keywords: *Breath analysis, bio-sniffer, biomarker, volatile organic compounds (VOCs), medical diagnosis*

Introduction

Exhaled breath offers a wealth of biological information, serving as a window into metabolic status, biological rhythms, and early indicators of various diseases. With over 3500 volatile organic compounds (VOCs) identified in human breath [**1**], several VOCs have shown promise as biomarkers for medical diagnostics. For instance, acetone levels are markedly elevated (75 ppm–1200 ppm) in cases of diabetic ketoacidosis (DKA), making it a potential candidate for non-invasive disease detection. Ethanol and its metabolites, such as acetaldehyde, can reflect liver function, while isopropanol is found at increased concentrations in individuals with certain cancers, like lung cancer, aiding in early screening. Methanol, which correlates with gut microbiota activity, can be used to monitor gut health.

In the field of metabolomics, biological samples—including breath, urine, blood, and cerebrospinal fluid are rich in chemical, physical, and biological data, particularly VOCs. [**2,3,4**]. Metabolites, closely tied to the metabolic processes of organisms, play a critical role in the onset and progression of diseases. These findings underline the significant diagnostic potential of VOCs as biomarkers across a range of health conditions.

Within human metabolomics, exhaled breath and skin stand out as the primary sources of volatile organic compounds (VOCs), each accounting for 54% of the total VOC profile. Other contributors include feces (15%), saliva (14%), urine (11%), and blood (6%) [**5**]. Remarkably, respiratory samples, saliva, and skin reveal 84, 360, and 532 unique exogenous and endogenous VOCs, respectively [**6,7**]. This underscores the rising significance of VOCs as biomarkers in disease diagnostics.

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Breath analysis, by evaluating VOC composition, facilitates real-time monitoring of metabolic status [**8,9**]. Its non-invasive and continuous monitoring nature eliminates the need for sample collection or processing, enhancing its utility in clinical medicine. Compared to blood tests, breath analysis minimizes discomfort while offering additional advantages, including effective tracking of physiological changes [**10, 11**].

Advancements in gas sensor technology have propelled its application across various domains, such as environmental quality testing, food safety assessments, and healthcare innovations. These developments reinforce the potential of breath analysis as a transformative tool in modern medicine [**12,13,14].**

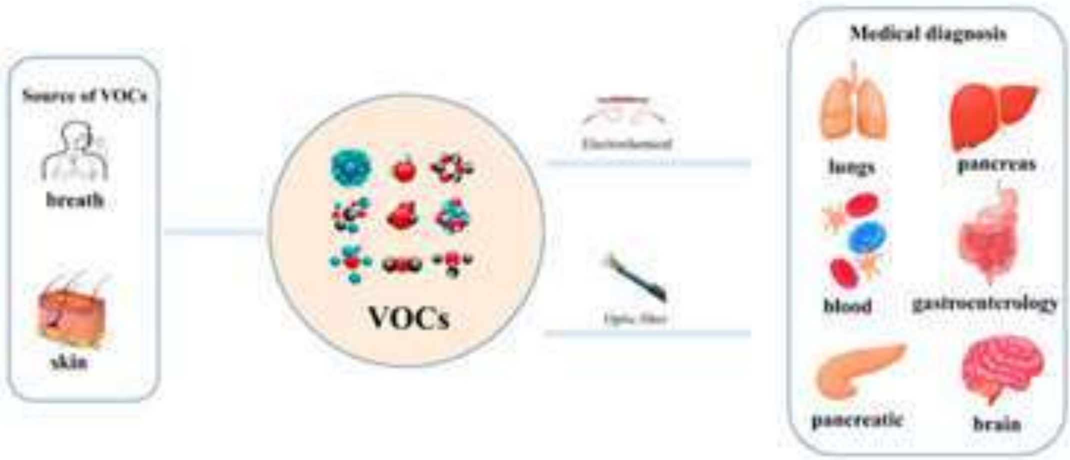


Figure 1. Identification of biomarkers related to specific diseases (e.g., lung diseases, liver diseases, gastrointestinal diseases, etc.) through the detection of VOCs in human exhaled and skin gases, utilizing both electrochemical and optical bio-sniffers.

This article sheds light on the dual aspects of challenges and applications surrounding bio-sniffer technology in medical diagnostics. It highlights how bio-sniffers leverage volatile organic compounds (VOCs) as biomarkers for real-time and non-invasive disease detection, offering promising solutions for monitoring metabolic and disease states. At the same time, it discusses existing challenges, such as enhancing detection sensitivity, ensuring device stability, and minimizing environmental interference, which remain critical for their broader adoption in clinical settings.

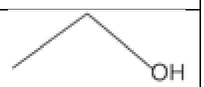
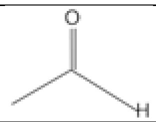
Characteristics of VOCs

2.1. Physical Properties and Chemical Structure of VOCs

Volatile organic compounds (VOCs) form a broad category of organic chemicals that readily evaporate at room temperature. Their chemical structures and physical properties vary significantly, encompassing simple alkanes like methane and complex polycyclic aromatic hydrocarbons. This diversity gives VOCs unique physical characteristics, such as colour, state under different conditions, boiling point, water solubility, and fat solubility, all of which influence their behaviour and migration pathways in the environment.

For example, VOCs with lower boiling points are more likely to volatilize at room temperature, whereas those with higher vapor pressures tend to escape from liquid or solid surfaces into the atmosphere [**15**]. VOCs with greater water solubility are more easily transported through aqueous systems, while those with higher fat solubility may accumulate within biological organisms. Understanding the chemical structures and physical properties of VOCs is crucial for predicting their environmental behaviour and evaluating their impacts on human health and the ecosystem. The physical properties of some common VOCs are listed in **Table 1**

Table1. Properties and chemical structures of common VOCs.

VOCs	Exterior Condition	Solubility	Molecular Formula	Vapour Pressure	Boiling Point	Structure
Ethanol	Colourless transparent liquid with aromatic odour	Soluble	C_2H_6O	43.9 mmHg (5.85 kPa)	78.3 °C	
Acetaldehyde	Colourless and transparent liquid	Soluble	C_2H_4O	520 mmHg (69.3 kPa)	21 °C	

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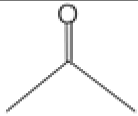
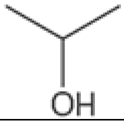
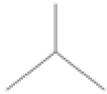
Acetone	Colourless and transparent liquid	Soluble	C_3H_6O	184 mmHg (24.5 kPa)	56.2 °C	
Isopropanol	Colourless and transparent liquid	Soluble	C_3H_8O	33.4 mmHg (4.45 kPa)	81–83 °C	
Methanol	Colourless liquid	Soluble	CH_4O	96.0 mmHg (12.8 kPa)	64.7 °C	
Methane	Colourless and odourless gas	Insoluble	CH_4	3.2 × 104 mmHg (4.27 × 103 kPa)	−161.5 °C	

2.2. Metabolic Processes in the Human Body

When volatile organic compounds (VOCs) enter the body through respiration, skin absorption, or ingestion, they are quickly transported into the bloodstream and tissues. Metabolic processes play a pivotal role in shaping their toxicity, biological effects, half-life, and associated health risks. Some VOCs, like benzene, produce highly reactive metabolic intermediates capable of interacting directly with cellular structures. This can lead to DNA damage, protein adduct formation, cellular dysfunction, and even carcinogenic outcomes. Therefore, comprehending the metabolic pathways of VOCs is essential for evaluating their potential health impacts and mitigating associated risks.

The majority of ethanol (80–90%) is absorbed through the gastric mucosa and intestine before entering the bloodstream, where it is metabolized in liver cells. Alcohol dehydrogenase (ADH) converts ethanol into acetaldehyde within the cytoplasm, which is further oxidized by aldehyde dehydrogenase (ALDH) into acetic acid. Acetic acid undergoes subsequent metabolism into carbon dioxide and water, releasing energy. [Figure 2]. This biochemical process generates significant amounts of reactive oxygen species (ROS), disrupting hepatic homeostasis and potentially leading to alcoholic liver disease (ALD)[**16**].

A smaller portion of ethanol (10–20%) is metabolized in hepatic microsomes via the cytochrome P450 enzyme system, primarily involving cytochrome P450 family 2-member E1 (CYP2E1) [**17**]. Ethanol can also undergo non-oxidative metabolic pathways, including:

- Sulfation: Ethanol is converted into ethyl sulfate (EtS) by sulfate transferases (SULTs) [**18**].
- Glucuronidation: UDP-glucuronosyltransferase (UGT) combines ethanol with uridine diphosphate glucuronic acid, forming ethyl glucuronic acid (EtG) [**19**].
- Phosphorylation: Phospholipid ethanol (PEth) is produced. [**20**]
- Esterification: Fatty acid ethyl esters (FAEEs) are generated. [**21**]

These enzymes are primarily expressed in the liver, and their metabolites are water-soluble, allowing excretion through urine. Although these non-oxidative pathways play a minor role in overall ethanol metabolism, they become more relevant in cases of excessive alcohol consumption, reducing toxic ethanol accumulation and its by-products. Clinically, metabolites from non-oxidative pathways serve as biomarkers for chronic or excessive alcohol intake. However, they can also lead to organ-specific damage, such as pancreatitis associated with FAEE accumulation in the pancreas.

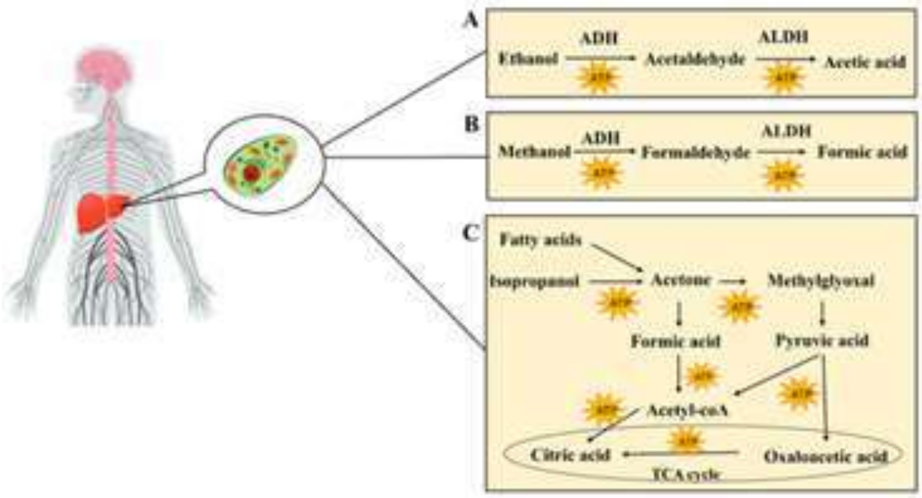


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Figure2 :(A) Metabolism of Ethanol in the Liver (B) Metabolism of Methanol in the Liver (C) Sources and Metabolism of Acetone

The concentration of acetone in exhaled breath is directly linked to the levels of ketone bodies in the bloodstream. In the human body, fatty acids undergo β-oxidation in the liver, leading to the production of ketone bodies, such as acetone, acetoacetic acid, and β-hydroxybutyric acid. Acetone levels are also influenced by the oxidation of isopropanol, primarily catalysed by alcohol dehydrogenase (ADH), as well as external factors like occupational exposure [**22**].

The metabolic pathways of acetone (Figure 2B) involve its conversion into compounds such as acetyl phosphoryl, formic acid, and methylglyoxal. Acetone may first transform into acetyl phosphoric acid, which is subsequently metabolized into formic acid and then acetyl-CoA, entering the tricarboxylic acid (TCA) cycle to generate energy. Alternatively, acetone can convert into methylglyoxal, which forms D-lactic acid and ultimately pyruvate. Pyruvate may either enter the TCA cycle or be converted into acetyl-CoA [**23**].

In diabetic patients, due to insulin deficiency, fatty acids are preferentially utilized as an energy source, making respiratory acetone a valuable non-invasive biomarker for detecting diabetic ketoacidosis (DKA). For non-diabetic individuals, respiratory acetone concentrations are typically below 1 ppm. Patients with well-managed diabetes exhibit moderately elevated levels, generally under 2 ppm. However, during DKA, respiratory acetone concentrations can spike dramatically, ranging from 75 ppm to 1200 ppm, offering a crucial diagnostic marker for clinical evaluation [**24**].

In mammals, methanol production is closely linked to the metabolic activities of the gut microbiota. These microorganisms generate methanol, which undergoes enzymatic reactions in the liver. Initially, alcohol dehydrogenase converts methanol into formaldehyde, followed by the oxidation of formaldehyde into formic acid via aldehyde dehydrogenase. These metabolites, formaldehyde and formic acid, may be excreted in the urine or further metabolized into carbon dioxide, completing the detoxification process. This cycle of enzymatic oxidation serves as the primary mechanism for methanol elimination within the body. [**25**]. The detection of methanol in exhaled breath offers a non-invasive means to evaluate gut microbiota activity and assess overall metabolic health.

Application of Bio-Sniffers in VOC Detection

3.1. Electrical Bio-Sniffers

Electrical bio-sniffers generate diverse electrical signals upon interacting with volatile organic compounds (VOCs) and are classified into types based on these signal variations, including chemical resistors, conductivity bio-sniffers, and electrochemical bio-sniffers. While they exhibit high sensitivity, electrical sensors often require periodic calibration to maintain performance [Table 3]. Additionally, reproducibility challenges may arise in environments with elevated temperature or humidity levels. Their specificity largely depends on selective coatings or surface modifications of nanomaterials, though their ability to distinguish between complex VOC mixtures remains limited, posing a challenge for broader applications [**26**].

Table 3. Electro-bio-sniffer for the detection of VOCs.

Sensing Methods	**Materials**	**VOCs**	**Performance**	**Results**	**Ref.**
Resistance	CuO	Toluene, methanol, isopropanol, acetonitrile, and acetone	Accurately and selectively detect volatile organic compound mixtures	93.8% accuracy rate	[**27**]
Resistance	MOS	Ethylbenzene and xylene	High sensitivity and long service life	Different nanoparticles are able to increase the response value under UV light excitation	[**28**]
Conductance	Sm_2O_3	Ethanol and acetone	High sensitivity, fast response, high selectivity, and stability	The tested bio-sniffer exhibits high sensitivity to low concentrations of ethanol and acetone, and shows a fast response to 20 ppm of ethanol	[**29**]
Conductance	Conductive polymers	Acetone, ethanol, and methanol	Good stability and repeatability	400 ppb for acetone, 150 ppb for ethanol, 300 ppb for methanol, and less than 10% of deviation in resistance change	[**30**]
CV	Fc@ZIF-8	Ammonia	High sensitivity and	Fc@ZIF-8 has a clear response to ammonia, which is about 3	[**31**]

			specificity	times more specific than the non-specific signal of cross-reactive gases	
CV	Ptm@Auto	Alcohol homologs	Good stability and repeatability	The normalized currents of Pt0.8@Auto NPs in methanol, ethanol, and isopropanol remained at the initial values of 69.6%, 68.7%, and 112.9%, respectively	[32]

3.2. Optical Bio-Sniffers

Optical bio-sniffers are a versatile group of instruments capable of detecting chemical interactions by measuring radiation intensity across infrared, visible, and ultraviolet spectra [33]. Common methods of optical sensing for VOCs include colorimetric sensors, fluorescent sensors, and optical fibre bio-sniffers (as summarized in Table 4). Among these, fluorescent sensors offer high specificity and are able to selectively detect specific VOCs using tailored fluorescent probes. However, their performance may decline due to fluorescence bursts, and periodic replacement of fluorescent probes is necessary to maintain optimal functionality.

Table 4. Reports common optical bio-sniffers for the detection of VOCs.

Sensing Methods	VOCs	Performance	Related Applications	Detection Range	Ref.
Colorimetric	Acetone, ethanol, and acetic acid	Results are provided fast and show high sensitivity	-	1 ppm, 0.1 ppm, 0.02 ppm	[34]
Colorimetric	28 VOCs	High sensitivity, high selectivity, and good stability	Efficiently differentiated between 5 human cancer cells and 2 normal human cells.	–	[35]
Luminous	Acetaldehyde	Has high sensitivity and specificity	Assess alcohol metabolism	20 ppb–10 ppm	[36]
Luminous	Acetone	Low power consumption and heat generation	Screening for diabetes	20 ppb–5300 ppb	[37]
Luminous	Isopropanol	High sensitivity and selectivity, wide dynamic range and real-time monitoring capability	Screening for type 2 diabetes	1 ppb–9060 ppb	[38]
Luminous	Methanol	High sensitivity	Assess the intestinal microbiota	0.32–20 ppm	[39]
Optic fiber	Ethanol	High sensitivity	Assess alcohol metabolism	25 ppb–128 ppm	[40]
Optic fiber	Ethanol	High sensitivity	Assess alcohol metabolism	1 ppb–3100 ppb	[41]
Optic fiber	Ethanol	High sensitivity	Assess alcohol metabolism	26 ppb–554 ppm	[42]

Challenges and Prospects

The application of bio-sniffers for monitoring VOCs in medical diagnostics presents several challenges, particularly in terms of sensitivity and selectivity. Although advancements have been made with electrical and optical bio-sniffers, improving their selectivity remains a significant hurdle. Researchers are actively investigating more efficient pre-concentration techniques and developing bio-sniffers with greater sensitivity to address this issue. Additionally, establishing a stronger and more precise correlation between VOC detection outcomes and specific diseases is crucial. Identifying characteristic VOC targets can enhance detection accuracy, broaden the spectrum of detectable diseases, and ultimately improve diagnostic capabilities. This ongoing research and refinement are vital to overcoming these challenges and realizing the full potential of bio-sniffers in clinical practice **[43].** Environmental factors, such as humidity and temperature fluctuations, significantly affect the performance of bio-sniffers, leading to inaccuracies in measurement. Temperature changes, for instance, alter the electrode reaction rate in electrochemical sensors and the fluorescence intensity in optical sensors, causing biased detection outcomes. Developing sensors that operate stably across a wide temperature range is crucial. High-temperature stable materials, like ceramic substrates, and sensors with low thermal coefficients can help reduce temperature-induced performance variability. Enhancing the bio-sniffer's immunity to environmental changes remains a pivotal research focus. Humidity stability, for example, can be addressed using hydrophobic substrates with porous micro-nano structures.

Interpreting the complex VOC data from respiratory samples poses another challenge, requiring sophisticated data processing techniques to improve diagnostic accuracy. Artificial intelligence (AI) technologies, such as neural networks for VOC pattern recognition, support vector machines (SVMs) for classification and regression, and principal component analysis (PCA) for dimensionality reduction and feature extraction, are increasingly used to address this challenge **[44].** Device integration is also a critical hurdle, involving the development of portable, user-friendly systems combining multiple bio-sniffers while preserving their detection capabilities. PVDF-based bio-sniffer arrays built with Cu MOFs, GAs, and dyes as responsive materials are now smartphone-compatible, enhancing accessibility.

Electrical bio-sniffers demonstrate great potential for integration and intelligent applications, while optical bio-sniffers excel in intelligence and miniaturization. Both technologies offer innovative solutions for diverse applications and efficient monitoring, paving the way for future advancements in VOC detection and medical diagnostics.

The future of bio-sniffers lies in the application of advanced materials and nanotechnology, which offer transformative potential for enhancing their performance. For instance, bio-sniffers based on 2D materials are showing promise in medical monitoring due to their unique physicochemical properties [**45,46,47].** The emergence of biofluorescence technology also holds great potential, particularly for early disease detection and real-time metabolic status monitoring, potentially paving a new path for bio-sniffers [**48,49**].

Deep learning algorithms are proving invaluable for identifying disease-related VOC patterns. As highlighted, bio-sniffer arrays have successfully distinguished 28 VOC types using techniques like principal component analysis (PCA), linear discriminant analysis (LDA), and hierarchical cluster analysis (HCA), significantly improving diagnostic accuracy and reliability. Progress in this field relies heavily on interdisciplinary collaboration, uniting experts from chemistry, biology, materials science, engineering, and data science to tackle technical hurdles and foster innovation. For example, electronic noses utilizing nanomaterials for VOC detection exemplify the power of cross-disciplinary efforts.

A notable trend is the combination of electrochemical and optical technologies, creating bio-sniffers with heightened sensitivity and selectivity. This convergence allows precise VOC biomarker identification, which is essential for early disease diagnosis and health monitoring. Multimodal detection capabilities further enhance these devices by integrating multiple methods on a single platform for more comprehensive and accurate analysis.

To ensure clinical adoption, large-scale validation studies and adherence to medical device regulations are imperative. While bio-sniffers show immense promise for medical diagnostics, overcoming challenges in technology, data processing, and integration remains crucial. Future breakthroughs in these areas will be key to advancing accurate disease diagnosis and health surveillance

Conclusions

This paper provides a comprehensive evaluation of the applications and challenges associated with bio-sniffers for monitoring volatile organic compounds (VOCs) in medical diagnostics. It delves into the detection mechanisms, performance attributes, and clinical relevance of both electrical and optical bio-sniffers. Electrical bio-sniffers stand out for their rapid response, high sensitivity, and portability, whereas optical bio-sniffers excel in non-contact detection, broad dynamic range, and high specificity.

Despite their promising capabilities, both types of bio-sniffers face obstacles, such as performance variability due to environmental factors like temperature and humidity fluctuations. To address these issues and drive technological advancement, future research must emphasize interdisciplinary collaboration to overcome current limitations and integrate biosensor technologies into clinical practices effectively. As research progresses and challenges are resolved, bio-sniffers are expected to play an increasingly vital role in medical diagnostics and health monitoring, offering innovative solutions for accurate and efficient disease detection.

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