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K.L.E. Society's

G. I. Bagewadi Arts, Science and Commerce College, Nipani-591237

Accredited at "A" level by NAAC with CGPA 3.10

IQAC INITIATIVE

One Day National Level Conference

Emerging Trends in Science and Technology

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K.L.E. Society's

G. I. Bagewadi Arts, Science and Commerce College, Nipani-591237

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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Chairman, KLE Society,
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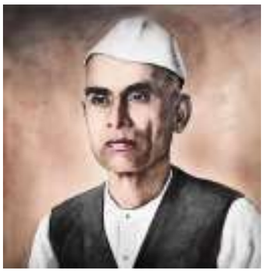

Sardar V. V. Patil

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
Dr. Atulkumar A. Kamble

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Original Article

AI in Society, Ethics, Governance and Education

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Abstract

The integration of AI in society, particularly in education, presents both transformative potential and ethical challenges. AI applications like ChatGPT offer personalized education and improved administration, but they also raise concerns about privacy, algorithmic fairness, transparency, student wellbeing, and accountability. A systematic literature review highlights five key ethical and governance areas: privacy and data protection, algorithmic fairness and bias, transparency and explainability, student well-being, and accountability through human oversight. This article explores the importance of Artificial Intelligence (AI), best practices of AI in society, governance and education. And also includes the advantages and AI driven threats in society. We will also explore the fundamentals of Artificial Intelligence (AI) and its growing impact across industries. You will learn to distinguish between AI and augmented intelligence and examine the evolution from traditional AI to generative AI. By the end of this paper, you will understand the capabilities of AI, limitations and role in enhancing human potentials.

Key Words: *Artificial Intelligence (AI), Education, Society, Ethics, Prompt Engineering, Generative AI, Machine learning.*

Introduction

The technologies of artificial intelligence (AI), and conversational models in particular, like ChatGPT, Google Gemini etc. have quickly become popular as a tool in the educational setting. The tools have the potential to enable tailored learning opportunities, increase student involvement, and promote the effective sharing of knowledge. However, together with these possibilities, the implementation of AI in the classroom also presents a mixed range of ethical and governance issues that have to be thoroughly analysed in order to achieve responsible implementation. Ethical problems are defined as issues related to fairness, responsibility, and privacy, while governance problems refer to the challenges posed by institutional policies and control mechanisms that ensure the responsible use of AI. AI is a technology that enables machines and computers to perform tasks that typically requires human intelligence. It helps systems learn from data, recognize patterns and make decisions to solve complex problems. It is also used in health care, finance, e-commerce and transportations offering personalized recommendations and enabling self-driving cars.

Definitions:

Artificial intelligence (AI): is the theory and development of computer systems capable of performing tasks that historically required human intelligence, such as recognizing speech, making decisions, and identifying patterns. AI is an umbrella term that encompasses a wide variety of technologies, including machine learning, deep learning, and natural language processing

Generative AI: Generative AI is a kind of artificial intelligence capable of producing original content, such as written text or images, in response to user inputs or "prompts." Machine learning (ML) is a subfield of artificial intelligence (AI) that focuses on developing algorithms that enable computers to learn from and make decisions based on data.

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Unlike traditional programming, where explicit instructions are given to the computer, machine learning allows the system to learn patterns and make predictions from data without being explicitly programmed for each task.

Some of the most common examples of AI in use today include:

- **ChatGPT:** Uses large language models (LLMs) to generate text in response to questions or comments posed to it.
- **Google Translate**: Uses deep learning algorithms to translate text from one language to another.
- **Netflix**: Uses machine learning algorithms to create personalized recommendation engines for users based on their previous viewing history.
- **Apple's Siri**: Apple's voice-activated personal assistant, Siri, is powered by deep neural networks (DNNs) to interact with users and complete their requests.

AI in India:

- **Economic Impact:** AI is projected to contribute $1.7 trillion to India's economy by 2035. The tech sector is expect ed to exceed $280 billion in revenue, with over 6 million people employed in the AI ecosystem.
- **Global AI Rankings**: India has made significant strides in global AI competitiveness, recently ranking third in the Stanford Global AI Vibrancy Tool, surpassing the UK and South Korea. This ranking reflects India's robust AI tale nt pool, research output, and strategic government policies.
- **AI Startups and Innovation**: India hosts around 1.8 lakh startups, with nearly 89% of new startups incorporating AI into their products or services. The country is becoming a hub for AI innovation, particularly in areas like healt hcare, education, and agriculture

AI impact summit 2026:

India will host the first-ever Global AI Impact Summit on February 19-20, 2026 in New Delhi, organized by MeitY. This landmark event, focusing on 'People, Planet, Progress,' aims to democratize AI for inclusive growth and social development, particularly for the Global South. It features the YUVAi program to foster youth innovation, bringing together global experts and innovators to shape AI's future.

India AI Impact Summit will focus on inclusive growth and featuring regional conferences and including YUAI to encourage youth participation and AI innovation, and it will bring together experts, leaders, world organizations, students and innovators from all over the world to discuss how the transformative power of AI serves humanity, drives inclusive growth, fosters social development and promotes people-centric innovation to protect our planet. This summit will be a major milestone in achieving the goal of 'Developed India' by 2047.

AI in Global:

By the end of 2025, global adoption of generative AI reached 16.3% of the world's population, up from 15.1% in the first half of the year — meaning roughly 1 in 6 people now use AI tools for learning, work, or problem-solving. While this marks rapid growth for a relatively new technology, the expansion is uneven: adoption in the Global North grew almost twice as fast as in the Global South, widening the gap from 9.8 to 10.6 percentage points. Artificial Intelligence (AI) is fundamentally reshaping contemporary education, not merely as a technical tool but as a transformative sociotechnical force. While often promoted for its potential to personalize learning and improve efficiency, this paper argues that AI's deeper impact lies in its capacity to reorganize relations of power, authority, and inequality within educational systems.

Types of AI:

Artificial Intelligence (**AI**) can be classified into two main categories — based on capabilities **and** based on functionalities — each offering a different perspective on how AI systems operate and evolve.

Based on Capabilities:

- **Narrow AI (Weak AI) Designed for a specific task**,

  Narrow AI excels in its domain but cannot perform outside its scope. *Examples:* Voice assistants like **Siri**, **Alexa**, facial recognition systems, and recommendation engines. These systems lack true understanding or awareness and dominate current AI applications.
- **General AI:**

  Artificial General Intelligence (AGI) is a theoretical form of artificial intelligence that possesses the ability to perform any intellectual task that a human can do. Unlike narrow AI, which is designed for specific tasks
- **superintelligence AI:**

Artificial superintelligence (ASI) is a hypothetical software-based artificial intelligence (AI) system with an intellectual scope beyond human intelligence. At the most fundamental level, this superintelligent AI has cutting-edge cognitive functions and highly developed thinking skills more advanced than any human.

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Based on functionalities:

1. Reactive Machine:

Reactive Machine AI is the most basic form of artificial intelligence, designed to respond to current inputs without storing past experiences. It operates purely on present data, making decisions based on predefined rules or algorithms without any memory or learning capability.

These systems are task-specific and deterministic

2. Limited memory:

Limited Memory AI is one of the most commonly used types of artificial intelligence in modern applications. Unlike reactive AI, which cannot learn from data, limited memory AI has the capability to retain past data for a limited time to improve decision-making and performance. This makes it ideal for tasks that require contextual understanding, such as self-driving cars, chatbots, and recommendation systems.

3. Theory of Mind AI:

Theory of Mind AI refers to the ability of artificial intelligence to understand and model human mental states, including thoughts, intentions, emotions, and beliefs. This capability allows machines to predict human behavior and in teract more naturally and empathetically with people. It is the world of AI.

4. Self aware AI:

The most sophisticated type of artificial intelligence is known as self-aware AI, in which computers acquire consciousness—the capacity to comprehend their surroundings, feelings, and the consequences of their actions.

Case Studies Of AI:

1. IBM Watson Health: Revolutionizing Patient Care with AI

Task/Conflict: The healthcare industry faces challenges in handling vast amounts of patient data, accurately diagnosing diseases, and creating effective treatment plans. IBM Watson Health aimed to address these issues by harnessing AI to process and analyze complex medical information, thus improving the accuracy and efficiency of patient care.

Solution: Utilizing the cognitive computing capabilities of IBM Watson, this solution involves analyzing large volumes of medical records, research papers, and clinical trial data. The system uses natural language processing to understand and process medical jargon, making sense of unstructured data to aid medical professionals in diagnosing and treating patients.

2.Amazon: Transforming Supply Chain Management through AI

Task/Conflict: Managing a global supply chain involves complex challenges like predicting product demand, optimizing inventory levels, and streamlining logistics. Amazon faced the task of efficiently managing its massive inventory while minimizing costs and meeting customer demands promptly.

Solution: Amazon employs sophisticated AI algorithms for predictive inventory management, which forecast product demand based on various factors like buying trends, seasonality, and market changes. This system allows for real-time adjustments, adapting swiftly to changing market dynamics.

3. Brainly's Use of Google Cloud's Vision AI

- **Overview:** Brainly, an online learning platform, partnered with Google Cloud to enhance its homework help servic es.
- **Technology:** The integration of Vision AI allowed students to photograph their questions and receive instant, relev ant answers.
- **Impact:** This solution democratized access to educational resources, particularly benefiting students who often lac k support

AI in Society and Education

Artificial Intelligence (AI) is fundamentally reshaping contemporary education, not merely as a technical tool but as a transformative sociotechnical force. While often promoted for its potential to personalize learning and improve efficiency, this paper argues that AI's deeper impact lies in its capacity to reorganize relations of power, authority, and inequality within educational systems.

Ethical and Social Challenges faced by AI:

1. Bias

- AI systems can inherit biases from the data they're trained on. If the training data is biased, the AI will likely reflect that bias in its outputs**.** This can lead to discriminatory outcomes, like an AI loan approval system favoring certain demographics.
- **Example:** An AI system trained on a dataset of news articles that primarily feature men in leadership roles might be more likely to recommend men for leadership positions in the future.

2. Transparency and Accountability

- It can be challenging to understand how complex AI systems make decisions. This lack of transparency makes it difficult to hold them accountable for any negative outcomes.

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- **Example:** An AI system used in criminal justice might deny parole to someone based on complex calculations, but it might be unclear why that decision was made, hindering any appeals process.

3. Impact on Jobs

- AI automation is likely to replace many jobs currently done by humans, potentially leading to widespread unemployment and economic disruption.
- **Example:** Automation in factories could lead to job losses for assembly line workers.

4. Widening Inequality

- Access to AI could worsen the existing social and economic inequalities. Those with access to powerful AI technology could become even more powerful, while those without access could be left behind.
- **Example:** Wealthy companies might leverage AI for further automation and profit, while smaller businesses struggle to keep up.

AI Driven Threats:

- Cyber attacks
- Privacy erosion
- Social polarization
- Economic inequality
- Loss of Human skills
- Financial Instability
- Healthcare risks

AI benefits and dangers

AI has a range of applications with the potential to transform how we work and live. While many of these transformations are exciting, like self-driving cars, virtual assistants, or wearable devices in the healthcare industry, they also pose many challenges. It's a complicated picture that often summons competing images: a utopia for some, a dystopia for others. The reality is likely to be much more complex. Here are a few of the possible benefits and dangers AI may pose:

Potential Benefits	Potential Dangers
Greater accuracy for certain repeatable tasks, such as assembling vehicles or computers.	Job loss due to increased automation.
Decreased operational costs due to greater efficiency of machines.	Potential for bias or discrimination as a result of the data set on which the AI is trained.
Increased personalization within digital services and products.	Possible cybersecurity concerns.
Improved decision-making in certain situations.	Lack of transparency over how decisions are arrived at, resulting in less-than-optimal solutions.
Ability to quickly generate new content, such as text or images.	Potential to create misinformation, as well as inadvertently violate laws and regulations.

Conclusion:

This research has demonstrated that the integration of Artificial Intelligence into the social fabric is not merely a technical evolution, but a profound shift in the human experience. As explored, Ethics cannot remain a theoretical luxury; it must be the foundational blueprint for development to prevent the scaling of historical biases. However, ethical guidelines lack teeth without robust Governance frameworks that balance innovation with accountability, ensuring that corporate interests do not supersede public safety.

Ultimately, the "human-in-the-loop" philosophy is only as effective as the humans involved. Therefore, Education emerges as the critical bridge, moving beyond basic digital literacy to foster a society capable of critical engagement with automated systems. We conclude that for AI to truly serve the common good, stakeholders must move away from siloed development and toward a multidisciplinary approach where policy, pedagogy, and philosophy are treated as essential as the code itself. The future of AI in society will not be defined by what the machines can do, but by the guardrails we choose to build around them.

References:

1. 60 Detailed Artificial Intelligence Case Studies [2026] - DigitalDefynd Education
2. Frontiers | AI in education: a sociological exploration of technology in learning environments

Journal of Research and Development
A Multidisciplinary International Level Referred and Double-Blind Peer Reviewed, Open Access
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3. https://www.geeksforgeeks.org/artificial-intelligence/types-of-artificial-intelligence/
4. India to host 100 countries for AI Impact Summit 2026: PM Modi, Sundar Pichai, and China delegation to attend
5. Superintelligence
6. Bostrom, N. (2014). Superintelligence: Paths, Dangers, Strategies. Oxford University Press.
7. Artificial Intelligence: A Guide for Thinking Humans
8. Mitchell, M. (2019). Artificial Intelligence: A Guide for Thinking Humans. Farrar, Straus and Giroux.
9. Weapons of Math Destruction
10. O'Neil, C. (2016). Weapons of Math Destruction. Crown.
11. European Commission (2019). Ethics Guidelines for Trustworthy AI.
12. UNESCO (2021). Recommendation on the Ethics of Artificial Intelligence.

Journal of Research and Development
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Original Article

Review Article Phthalazine-Based Metal Complexes for Luminescence, Sensing, and OLED Applications

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Abstract

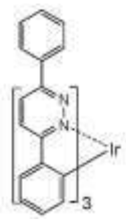
Phthalazine derived iridium complexes have been synthesised and studied for their OLED applications. Presence of nitrogen at 1,2 positions will facilitate complexes with higher nuclearity. It was found that ligands bearing C^N=N structuref in Ir complexes could bond to the Ir atom more strongly, and could also create a ''proximity effect,'' compared to their counterpart ligands with chelating N atoms bearing adjacent sp^2 C atoms (represented as C^N=CH), such as Ir(ppy)3 (tris(2-phenylpyridine) iridium). In the present review paper few Ir-Phthalazine complexes were analysed for the OLED applications.

Keywords: *Phthalazine, Iridium Complex, OLED applications, Proximity effect.*

Introduction

Azo heterocycles are the most frequent used ligands in coordination chemistry. These have been played a crucial role in synthesis and properties of coordination compounds owing to their gigantic ability form bond with metal. Nitrogen is neither that soft nor that hard, so it can form bond with soft metal and hard metals as well. Pyridine analogues have been found to be very potent coordinating molecules. A fused diazine compounds, phthalazine is have special structural features which yields crucial application in various fields. Phthalazine derived iridium complexes have been synthesised and studied for their OLED applications. Presence of nitrogen at 1,2 positions will facilitate complexes with higher nuclearity. To facilitate bimetallic complex the phthalazine core itself brigdes the two metal centres. Bimetallic complexes have been used as catalyst. Phthalazine Ir complexes have shown higher efficiency compared to quinioline derivatives. It was found that ligands bearing C^N=N structure in Ir complexes could bond to the Ir atom more strongly, and could also create a ''proximity effect,'' compared to their counterpart ligands with chelating N atoms bearing adjacent sp^2 C atoms (represented as C^N=CH), such as Ir(ppy)3 (tris(2-phenylpyridine) iridium). Phthalazine derived Ir complexes are promising for optoelectronic applications due to their strong phosphorescence and high thermal stability.

Table showing Ir complexes studies for efficient OLED materials and with longer wavelength photoluminescence:

 1	 2

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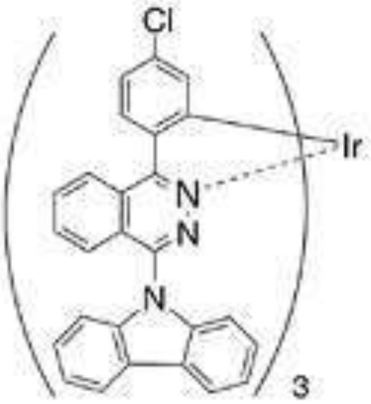
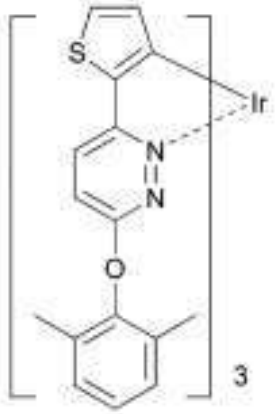
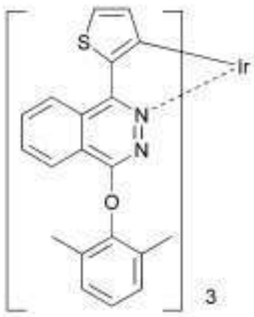
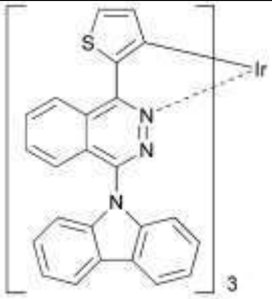
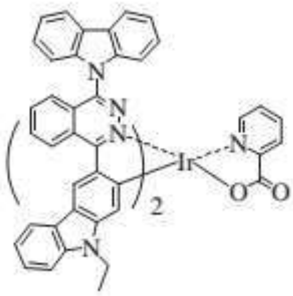
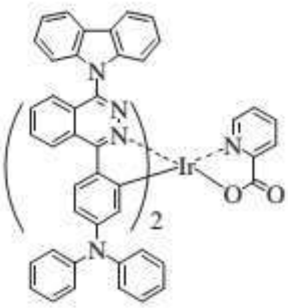
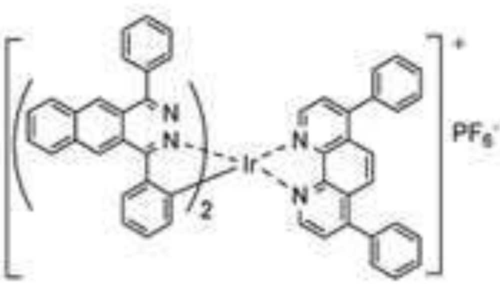
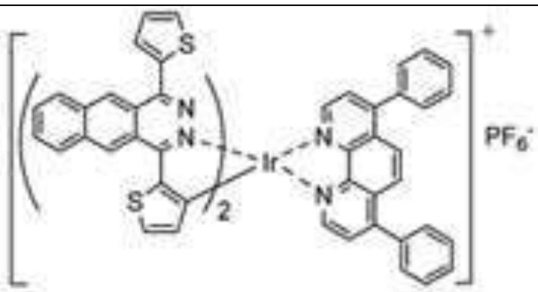
 3	 4
 5	 6
 7	 8
 9	 10

Chlorobenzene and dimethylphenoxy substituted Phthalzine derived cyclometallated complex are used as dopant in light emitting diodes. Complex **1** was doped into a host PVK-IBP blend. Host at different doping ratios under excitation of 325 nm line from a He-Cd laser. Fluorescence efficiency increased from 84.21 % to a maximum of 95.3% goes from low to intermediate dopant concentration (0.5 to 4 wt %) and then decreased with increasing concentration. Dopant was found too very compactable. This composition exhibited a peak electrophosphorescnece wavelength at

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597nm along with a shoulder around 635nm. A peak external quantum efficiency of 20.2% ph el^{-1} and luminescence efficiency of 18.4 Cd A^{-1} were recorded at a current density of the 0.49 mA cm^{-2} and a luminescence of 5870 Cd m^{-2} was observed at a current density of 114 mA $cm^{-2.}$ Residual emission not from host is not observed in electroluminescence spectra at high drive currents. At high current combination of triplet-triplet annihilation has led to typical efficiency roll off. High external quantum efficiency that of 20% ph el^{-1} is an indication of balanced electron and hole recombination in the host matrix. Presence of strictly hindred phenolic spacer decreasing the self-quenching of phosphor and corresponding increase in luminescence efficiency [01].

Ir complexes of Biphenyl substituted phthalazine derivatives are synthesised. They have found that phthalazine containing C^N=N structures can form strong bond with Ir thereby enhancing the stability, less steric repulsion due to absence of C-H hydrogen. They have compared phtoluminiscence properties of with corresponding C^N=CH analogue. The HOMO – LUMO gap in the C^N=N have larger and hence they have smaller phtoluminiscence emission. They have also studied the electroluminescence property of **2** by doping into CBP host with high doping concentration of 10% the efficiency dropped significantly and was probably related triplet-triplet annihilation at the high excitation density. The 5% Ir complex doped device presented best performance with electrolumiscence efficiency 8.3% and CIE coordination (0.69, 0.30). Electrochemical studies have shown that **2** is electrochemically stable with reversible oxidation and reduction (vs. Ag/AgCl) of 1.03 and 1.88 V [2].

In order to facilitate efficient mixing of singlate and triflate excited states, Yaun fang have incorporated cabazole unit into phthalazine which is beneficial to improve the charge balance in the electroluminicsnet process and enhance thermal stability. Complex **3** has shown strong photoluminiscence in DCM at 615 nm upon excitation of 400nm quantum yield of 0.46. Electrochemical properties of **3** show no clear reduction peak in DCM. Ir(CPC)3 is used as a dopant in a device structure ITO/PEDOT (45 nm)/ 2 wt% Ir (CPC)3+ 68 wt% VK+ 30 wt% PBD (80 nm)/ TPBI (30 nm)/Ba (4 nm)/Al (100 nm). The Ir (CPC)3 doped device has a maximum emission at 620nm Electroluminiscence emission originates from a mixed

3MLCT/3pi–pi [3]. Tris-cyclometalated iridium (III) complexes with pyridazine and phthalazine 4, **5** and **6**. The iridium complexes-based OLEDs fabricated by spin-coating technique exhibited promising performance. At 4 wt% doping level and a practical luminance of 100 cd m^{-2}, the external quantum efficiencies of the devices using **4**, **5** and **6** as dopants reached 9.0, 6.9 and 9.3% photons/electron, respectively [4]

Introducing triphenylamine unit instead of carbazole unit led to a red shift of 14nm in photoluminiscence spectrum of Ir(III) complex. This suggested that the carbazole moiety of this material increased the band gap energy. The PBD and PVK blend was doped with complexes **7** and **8** to explore its electroluminescent properties and 30% (w/w) PBD loaded blend showed excellent EL property compared to the blends with different PBD loadings.

The electroluminescent spectra of the complexes **7** and **8** for OLEDs were investigated. A weak emission at about 438 nm from PVK-PBD blend and low doping concentrations was found and disappeared at 4 wt.% doping concentrations. While no characteristic emissions from the host at low doping concentration. The absence of any emission peaks of host materials indicated that energy and charge transfer from the host exciton to the phosphor was efficient under electrical excitation.

Comparison study was made between benzoquinone and benzophthalazines derivatives with respect to more efficient complexes. Complex **11** shown bit red shift compared to **10**.

Photoluminescence spectra of complexes **10** and **11** have fall in NIR region with a significant red emiting iridium complex with substituted cyclometallated phenyl phthalazine ligand complex **10** has emission peak at 715 nm and 788 nm and complex **11** has shown emission peak at 775 nm where there is phenyl and triphenyl amines substitutes are there respectively. Electrophophsorescent device designed PVK-PBD blend host and complexes and **10** and **11** dopants. PVK-PBD blend host shown emission band at 415nm which can be quenched when doping concentration increased to 20% and intense NIR emission was detected at 715 nm and 788 nm for device with **10** and 791nm with **11**. They report an interesting observation, with complex one peak having longer wavelength is shown much stronger intensity compared to peak at shorter wavelength. Further emission intensity at longer wavelength increases with increase in doping concentration [5].

Conclusion

In summary, phthalazine-derived iridium complexes deliver a promising class of phosphorescent materials for OLED applications, out of the unique 1,2-dinitrogen structure to enable higher nuclearity and strong metal-ligand interactions. The C^N=N chelating arrangements provides superior bonding strength and a beneficial "proximity effect" compared to traditional C^N=CH ligands, such as those in $Ir(ppy)_3$, resulting in improved photophysical properties, including higher quantum yields, red-shifted emissions, and greater device stability.

References

1. Bihai Tong, Qunbo Mei, Shuanjin Wang, Yuan Fang, Yuezhong Meng, and Biao Wang, J. Mater. Chem., 2008, 18, 1636–1639
2. Bao Xiu Mi, Peng Fei Wang, Zhi Qiang Gao, Chun Sing Lee, Shuit-Tong Lee, Hui Ling
3. Hong, Xiao Ming Chen, Man Shing Wong, Ping Fang Xia, Kok Wai Cheah, Chin H. Chen,

Journal of Research and Development
A Multidisciplinary International Level Referred and Double-Blind Peer Reviewed, Open Access
ISSN : 2230-9578 | Website: https://jrdrvb.org Volume-18, Issue-2(VI)| February- 2026

and Wei Huang, Adv. Mater., 2009, 21, 339–343
4. Yuan Fang, Bihai Tong, Sujun Hu, Shuanjin Wang, Yuezhong Meng, Junbiao Peng, and Biao Wang, Organic Electronics, 2009, 10, 618–622
5. Nan Tian, Alexander Thiessen, Ralf Schiewek, Oliver J. Schmitz, Dirk Hertel, Klaus Meerholz, and Elisabeth Holder, Synthetic Metals, 2010, 160, 2231–2238
6. Qunbo Mei, Lingxia Wang, Bo Tian, Bihai Tong, Jiena Weng, Bin Zhang, Yuanzhi Jiang, and Wei Huang, Dyes and Pigments, 2013, 97, 43–51

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Original Article

An Adaptive Cybersecurity Framework for Continuous Risk Management Using AI-Driven Automation

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Abstract

Cybersecurity frameworks such as NIST CSF, ISO/IEC 27001, and RMF are widely used to manage organizational cyber risk. However, existing research primarily focuses on compliance and conceptual adoption, often lacking quantitative effectiveness metrics, real-time adaptability, and integration with emerging technologies. This paper proposes an adaptive cybersecurity framework that harmonizes established standards with AI-driven automation, predictive analytics, and continuous risk assessment. The framework introduces measurable risk indicators, automated control validation, and real-time threat intelligence integration. It is designed to address modern domains such as cloud-native systems, AI platforms, IoT, and software supply chains. By enhancing traditional frameworks with automation and continuous adaptation, this work provides a scalable, measurable, and practical approach to cyber risk management.

Keywords: *Cybersecurity framework, risk management, NIST CSF, ISO/IEC 27001, AI-driven security, continuous risk assessment, automation, cyber resilience*

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Introduction

Cybersecurity risk management is becoming increasingly complex due to rapid digital transformation, cloud adoption, AI deployment, and interconnected supply chains. Organizations face evolving threats that static security controls cannot address. Traditional frameworks such as NIST CSF, ISO/IEC 27001, and RMF guide risk identification, assessment, and mitigation.

However, existing implementations are often compliance-driven and periodic, leaving organizations exposed to rapidly emerging threats. For example, ransomware attacks on critical infrastructure and supply chain vulnerabilities (e.g., Log4j) demonstrate that static frameworks fail to prevent dynamic, high-impact attacks. Moreover, research rarely evaluates measurable risk reduction or integrates advanced technologies like AI and automation.

This paper proposes an enhanced cybersecurity framework addressing these gaps by incorporating continuous risk adaptation, quantitative risk metrics, and AI-driven automation while maintaining alignment with established standards.

Limitations of Existing Cybersecurity Framework Research

A. Lack of Quantitative Risk Measurement

Most studies describe frameworks qualitatively, focusing on policy alignment and control coverage, but rarely quantify how much risk is actually reduced. Without measurable indicators, organizations cannot objectively evaluate framework effectiveness.

B. Static and Periodic Risk Assessment

Traditional frameworks rely on scheduled assessments (annual or quarterly) that fail to capture real-time threat dynamics, leaving organizations vulnerable to zero-day exploits and emerging attack vectors.

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C. Limited Automation and Intelligence Integration

Manual processes dominate control validation, risk scoring, and compliance reporting, increasing operational cost and delaying responses, especially in large-scale environments.

D. Insufficient Coverage of Emerging Threat Domains

Existing research provides limited guidance for AI systems, cloud-native architectures, IoT ecosystems, and software supply chains—all domains with unique risk profiles inadequately addressed by traditional frameworks.

Proposed Adaptive Cybersecurity Framework

A. Framework Overview

The proposed framework enhances existing standards with **four integrated layers**:

1. Cross-Framework Integration Layer
2. AI-Driven Risk Intelligence Layer
3. Continuous Risk Monitoring Layer
4. Quantitative Risk Measurement Layer

This layered approach preserves compliance while enabling adaptability, scalability, and measurable risk management.

B. Cross-Framework Integration Layer

Instead of treating frameworks independently, this layer harmonizes NIST CSF, ISO/IEC 27001, and RMF via unified control mapping. Overlapping controls are consolidated, reducing redundancy and improving operational efficiency.

Benefit: Organizations can achieve multi-standard compliance through a single unified workflow, saving time and resources.

C. AI-Driven Risk Intelligence Layer

AI enhances decision-making and transforms frameworks from static guidelines into intelligent systems:

- **Machine learning models:** Analyze historical incidents, vulnerability patterns, and threat intelligence feeds.
- **Predictive analytics:** Forecast risk escalation for critical assets and identify high-likelihood attack scenarios.
- **Automated risk scoring:** Prioritizes controls based on impact, probability, and exploitability.

Data sources: Security logs, network telemetry, vulnerability scanners, and external threat intelligence feeds feed the AI models to generate actionable insights in real time.

D. Continuous Risk Monitoring Layer

Continuous monitoring uses **real-time data streams** to dynamically update risk scores and enforce adaptive controls:

- **Security telemetry:** Firewall, endpoint, and network logs
- **Vulnerability scanning:** Automated scans of software and systems
- **Threat intelligence feeds:** Public and private cyber threat sources

This enables real-time mitigation, reducing the window of exposure to emerging threats.

E. Quantitative Risk Measurement Layer

To evaluate framework effectiveness, three key metrics are introduced:

1. **Risk Reduction Index (RRI):** Measures reduction in overall risk exposure

$$\text{RRI (\%)} = \frac{R_{\text{before}} - R_{\text{after}}}{R_{\text{before}}} \times 100$$

Example: If overall risk exposure score reduces from 80 to 50, RRI = ((80-50)/80) *100 = 37.5%.

2. **Incident Frequency Ratio (IFR):** Measures change in security incident frequency over time

$$\text{IFR} = \frac{\text{Incidents}_{\text{after}}}{\text{Incidents}_{\text{before}}}$$

Example: If incidents drop from 20 to 8 per year, IFR = 8/20 = 0.4 (60% reduction).

3. **Control Effectiveness Score (CES):** Measures performance of implemented controls

$$\text{CES} = \frac{\text{Controls Effective}}{\text{Total Controls}} \times 100$$

Example: 18 out of 20 controls perform effectively → CES = 90%.

These metrics enable objective evaluation of framework performance and continuous improvement.

IV. Application to Emerging Cyber Domains

A. Cloud and Develops Environments

Supports dynamic asset discovery, continuous compliance monitoring, and automated policy enforcement in cloud-native systems.

B. Artificial Intelligence Systems

Evaluates AI-specific risks, such as model poisoning, inference attacks, and data integrity, using continuous monitoring and specialized control mappings.

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C. IoT and Cyber-Physical Systems (CPS)

Accounts for device heterogeneity, limited resources, and operational continuity risks common in IoT and CPS environments.

D. Supply Chain Risk Management

Assesses third-party and software supply chain risks via continuous vendor risk scoring and dependency analysis, addressing vulnerabilities like Log4j or malicious updates.

Conclusion

This paper presents an adaptive cybersecurity framework that integrates AI-driven automation, continuous monitoring, and quantitative risk measurement with established standards. By addressing critical research gaps, it transforms cybersecurity frameworks from static compliance tools into dynamic, intelligent risk management systems. The framework is suitable for modern digital environments and provides a practical foundation for enhancing organizational cyber resilience.

References

1. National Institute of Standards and Technology, Framework for Improving Critical Infrastructure Cybersecurity, 2024.
2. National Institute of Standards and Technology, Risk Management Framework (SP 800-37 Rev. 2), 2018.
3. ISO/IEC, ISO/IEC 27001 Information Security Management Systems, 2022.
4. ISO/IEC, ISO/IEC 27005 Information Security Risk Management, 2022.
5. ISO, ISO 31000 Risk Management — Guidelines, 2023.
6. M. Rahman et al., “Assessing cybersecurity risk management frameworks,” IEEE Conf. Publications, 2024.
7. A. Lokare et al., “Integrating cybersecurity frameworks into adaptive IT security,” arXiv, 2025.
8. S. Ee et al., “Adapting cybersecurity frameworks to manage AI risks,” arXiv, 2024.

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Original Article

Green and Sustainable Chemistry and Its Applications

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Abstract

Green and sustainable chemistry provides a framework for designing chemical products and processes that reduces environmental impact, enhance resource efficiency and protect human health. This article examines 12 principles of green chemistry, their evolution into sustainable practices and diverse applications in pharmaceuticals, materials science, energy, agriculture, and nanotechnology. Case studies, such as BASF's ibuprofen synthesis and Pfizer's sitagliptin production, illustrate waste reductions exceeding 80%. Metrics like process mass intensity (PMI) and life cycle assessment (LCA) enable rigorous evaluation. Despite challenges like scalability and costs, recent advances including AI-optimized catalysis, Deep Eutectic Solvents (DES), and biocatalysis signal transformative potential. By 2026, these approaches align with global sustainability goals, promoting a circular economy and reduced emissions across industries.

Keywords: *Green chemistry, Sustainable chemistry, Atom economy, Catalysis, Circular economy, Life cycle assessment.*

Introduction

The chemical industry drives innovation but generates substantial waste, hazardous byproducts, and greenhouse gases, contributing to environmental degradation. Traditional end-of-pipe treatments prove inefficient and costly. Green chemistry, pioneered by Anastas and Warner in 1998, shifts paradigms by preventing pollution at the source through molecular design.

Sustainable chemistry expands this to holistic systems, incorporating economic, social, and environmental dimensions via life cycle thinking. By 2026, amid climate urgency and regulations like the EU Green Deal, adoption yields economic benefits—waste reductions translate to billions in savings annually. This review synthesizes principles, applications, metrics, case studies, barriers, advances, and prospects, drawing on 20 key references for comprehensive insight.

Global production exceeds 500 million metric tons yearly, with green methods cutting sector emissions by 20-50% in leaders like BASF and Pfizer. Drivers include renewable feedstocks, benign solvents, and catalysis, fostering circularity where outputs become inputs.

The 12 Principles of Green Chemistry

The foundational 12 principles guide sustainable design (Anastas & Warner, 1998).

Principles 1-6: Waste Prevention and Design

1. **Prevention**: Prioritize avoiding waste over remediation, targeting zero byproducts.
2. **Atom Economy**: Maximize reactant incorporation into products, quantified as (product MW / reactants Σ MW) × 100%. Ideal >90%.
3. **Less Hazardous Synthesis**: Use and generate low-toxicity substances.
4. **Safer Chemicals**: Maintain efficacy with reduced toxicity via QSAR modeling.

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5. **Safer Solvents/Auxiliaries**: Replace VOCs with water, supercritical CO_2, ionic liquids, or DES, now in 25% of new processes.
6. **Energy Efficiency**: Minimize demands through ambient conditions, microwaves, or flow systems, cutting usage 50-90%.

Principles 7-12: Renewability and Safety

7. **Renewable Feedstocks**: Shift from fossils to biomass/CO_2.
8. **Reduced Derivatives**: Eliminate unnecessary steps.
9. **Catalysis**: Prefer catalysts (TON >1,000) over stoichiometric reagents.
10. **Design for Degradation**: Ensure post-use breakdown to innocuous materials.
11. **Real-Time Monitoring**: Prevent hazards via in-process analysis.
12. **Safer Processes**: Minimize explosion/fire risks through intensification.

These principles underpin green analytical chemistry (GAC), optimizing labs for minimal reagents. Modernization efforts, as in 2026 RSC perspectives, integrate AI and circularity.

Evolution to Sustainable Chemistry

Green chemistry's molecular innovations evolved into sustainable chemistry's systems approach by 2020, addressing supply chains via LCA and circular economy (CE) metrics. Critiques of narrow focus prompted integration of social equity and biodiversity.

Post-2020 surges include DES for extractions (viscosity-tuned, biodegradable), biocatalysts for >99% selectivity, and continuous flow for scalability. AI retro synthesis predicts green pathways, slashing experiments 70-80%. Conferences like the 30th GC&E (2026) and MAGSuC highlight interdisciplinary.
Education via ACS summer schools embeds principles early.

Applications in Key Industries

Pharmaceuticals

High E-factors (25-100) spur green routes. Enzymes replace metals; transaminases achieve 99% ee, 85% waste cuts.

Drug	Traditional PMI	Green PMI	Key Innovation
Ibuprofen	77	5	Catalytic HF process
Sitagliptin	45	6	Bio transamination
Sertraline	560	4.8	Shorter steps

Flow manufacturing integrates GAC for real-time purity.

Materials Science

Bio-polymers like PHA (bacterial, 100% degradable) supplant PET. Coca-Cola's PlantBottle® hits 100% bio-content by 2026. CO_2 polycarbonates reach 50% renewable carbon.
Mechanochemistry enables solventless synthesis, energy savings 90%.

Energy and Fuels

Lignocellulosic biofuels use DES pretreatment (yields +50%). Photocatalysis splits water for H_2; ZnO nanoplatforms treat wastewater. PFAS-free batteries employ bio-electrolytes.

Agriculture

Neem biopesticides degrade in days. GAC sensors monitor soils reagent-free.

Nanotechnology

Plant-mediated AgNPs offer antimicrobial coatings, replacing toxic reductants.

Metrics for Greenness Assessment

Quantitative tools validate progress.

- **PMI**: Total mass in / product mass out (pharma target <20).
- **E-Factor**: Waste / product (bulk <1, pharma <5).
- **LCA**: ISO 14040 cradle-to-grave analysis.

Metric	Formula	Benchmark	Sector Example
Atom Economy	(Prod. MW / React. Σ MW) × 100	>90%	Additions
PMI	Inputs / Outputs	1-10	Fine chem.
Carbon Efficiency	C in prod. / C in feed	>60%	Renewables

GREENSCOPE software provides dashboards. Flow cuts PMI 60%.

Case Studies

- **BASF Ibuprofen**: 1990s green route: 99% yield, PMI 5 (vs. 77), avoids 4,000 tons waste/year. ROI <2 years.
- **Pfizer Sitagliptin**: 2011 enzyme process: 88% yield, 85% waste drop, scales to tons.

- **Novozymes Enzymes**: Detergents save 40% energy globally.
- **PlantBottle®**: Bio-ethylene glycol, recyclable, 30% lower footprint.

LCAs confirm 40% emission cuts.

Challenges and Barriers

Capital costs burden SMEs (ROI 2-5 years). Catalysts deactivate; green solvents scale variably. Regulations fragment globally; developing regions lack infrastructure.
Social LCA lags; IP stifles sharing.

Recent Advances (2020-2026)

On-water reactions avoid solvents. DES stabilize nanoparticles; AI designs self-assembling materials. Electrified synthesis (plasma) halves temperatures. Bio-opioids via yeast: 100x efficiency. 2026 trends: carbon capture, scalable DES.

Future Directions

AI-blockchain for LCAs; policies like carbon taxes. Hubs like MAGSuC 2026 drive collaboration. Projections: 50% emission cuts by 2035. Training via GC&E ensures workforce readiness.

Conclusion

Green chemistry embeds prevention, driving industrial regeneration. With metrics and innovations, it realizes SDGs, turning challenges into opportunities.

References

1. American Chemical Society. (2026). Green chemistry & sustainability. https://www.acs.org/green-chemistry-sustainability.html[acs]
2. Anastas, P. T., & Warner, J. C. (1998). Green chemistry: Theory and practice. Oxford University Press. [en.wikipedia]
3. CAS. (2026). Green chemistry: Six key trends. https://www.cas.org/resources/cas-insights/green-chemistry-trends[cas]
4. International Journal of Pharmaceutical Research and Technology. (2025). Sustainable development, green chemistry. https://ijprt.org/index.php/pub/article/view/665[ijprt]
5. National Center for Biotechnology Information. (2024). Green analytical chemistry. https://pmc.ncbi.nlm.nih.gov/articles/PMC11772533/[pmc.ncbi.nlm.nih]
6. National Center for Biotechnology Information. (2021). Systems-based green chemistry. https://pmc.ncbi.nlm.nih.gov/articles/PMC8654969/[pmc.ncbi.nlm.nih]
7. Royal Society of Chemistry. (2025). Systematic review of green chemistry. https://pubs.rsc.org/en/content/articlehtml/2025/rp/d4rp00166d[pubs.rsc]
8. Royal Society of Chemistry. (2026). Modernizing 12 principles. https://pubs.rsc.org/en/content/articlehtml/2026/gc/d5gc05289k[pubs.rsc]
9. Sheldon, R. A. (2021). Metrics of green chemistry. ACS Sustainable Chemistry & Engineering, 9(4), 1565-1575. [grc]
10. U.S. EPA. (2026). Basics of green chemistry. https://www.epa.gov/greenchemistry/basics-green-chemistry[epa]
11. Wikipedia. (2026). Green chemistry. https://en.wikipedia.org/wiki/Green_chemistry[en.wikipedia]
12. ACS GCI. (2025). Summer school. https://www.acs.org/green-chemistry-sustainability/education/summer-school.html[acs]
13. ACS. (2025). 12 principles. https://www.acs.org/green-chemistry-sustainability/principles/12-principles-of-green-chemistry.html[acs]
14. Current Research in Green and Sustainable Chemistry. (2025). Journal homepage. https://www.sciencedirect.com/journal/current-research-in-green-and-sustainable-chemistry[sciencedirect]
15. Frontiers in Chemistry. (2025). Green section. https://www.frontiersin.org/journals/chemistry/sections/green-and-sustainable-chemistry[frontiersin]
16. GCANDE. (2026). 30th conference. https://www.gcande.org[gcande]
17. Gordon Research Conferences. (2026). Green chemistry conf. https://www.grc.org/green-chemistry-conference/2026/[grc]
18. MAGSuC. (2026). Modern aspects. https://snuadmissions.com/magsucs/magsucs.html[snuadmissions]
19. PMC. (2024). Harnessing 12 principles. https://pmc.ncbi.nlm.nih.gov/articles/PMC11184551/[pmc.ncbi.nlm.nih]
20. Principles of green chemistry. (n.d.). https://d-nb.info/1368979114/34[d-nb]

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Original Article

Cybersecurity in FinTech Payments and E-commerce: AI-Driven Threats, Zero Trust, and Emerging Security Trends

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Abstract

The rapid growth of digital finance—including FinTech platforms, online payment gateways, and e-commerce marketplaces—has revolutionized global financial systems while significantly expanding the cyber-attack surface. Sophisticated attacks such as AI-generated deepfakes, automated malware, ransomware, and synthetic identity fraud now threaten financial transactions. In response, cybersecurity strategies are evolving toward decentralized models, AI-enabled detection systems, Zero Trust architectures, and quantum-safe cryptography. This paper synthesizes recent academic research and industry developments (2025–2026), covering threat taxonomies, defensive strategies, emerging attack vectors, and regulatory enhancements in payment authentication. The integration of these trends underscores the necessity of robust, AI-driven, and compliance-aware security architectures for securing modern financial ecosystems.

Keywords: *FinTech cybersecurity, AI-driven payment security, Zero Trust architecture, deepfake fraud detection, regulatory authentication frameworks, quantum-resistant cryptography*

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Introduction

Digital finance technologies—including FinTech applications, mobile wallets, and e-commerce platforms—are transforming how payments and transactions occur worldwide. While these innovations offer convenience and speed, they have also expanded the cybersecurity attack surface. Threat actors increasingly exploit vulnerabilities in payment gateways, APIs, and identity authentication mechanisms, employing advanced tactics such as AI-generated deepfakes, malware, ransomware, and synthetic identities. Traditional security systems are proving insufficient, necessitating a paradigm shift toward:

- Zero Trust architectures for granular access control,
- AI-driven threat detection and monitoring, and
- Regulatory compliance integration to reduce financial risks.

This paper provides a comprehensive review of cybersecurity frameworks, analyzes evolving threats, and highlights emerging solutions critical to safeguarding digital payment ecosystems.

Emerging Threat Landscape

A. AI-Powered Fraud and Deepfakes

- AI-generated synthetic identities, deepfake audio, and video are increasingly used to manipulate authentication systems.
- Fraudsters exploit behavioral anomalies in e-commerce transactions, bypassing standard security measures.
- Real-time AI-driven monitoring, behavior analytics, and anomaly detection are essential to counteract these threats.

B. Ransomware and Double Extortion

- Modern ransomware attacks now include data exfiltration and double-extortion techniques.

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- FinTech infrastructure is a prime target due to its reliance on sensitive financial data.
- Automated ransomware tools can propagate quickly, highlighting the need for proactive monitoring and backups.

C. Identity and Credential-Based Attacks

- Identity compromise remains the most exploited attack vector.
- Attackers leverage AI to bypass multi-factor authentication (MFA), password reset flows, and account recovery mechanisms.
- Credential stuffing, phishing, and social engineering are increasingly sophisticated, requiring adaptive defenses.

D. Supply Chain and API Vulnerabilities

- E-commerce and FinTech platforms rely heavily on third-party APIs, creating a large attack surface.
- Misconfigured APIs and third-party vulnerabilities can lead to data leaks and transaction fraud.
- Continuous Exposure Management (CEM) and supply chain risk assessment are essential preventive measures.

E. Emerging Threats

- **Man-in-the-Middle (MITM) attacks:** Targeting mobile wallets and payment apps.
- **Insider threats:** Employees or contractors with privileged access misusing data.
- **IoT and smart device exploitation:** IoT devices used in payment or delivery systems can be hijacked for attacks.
- **Cryptojacking and AI-powered malware:** Exploiting user devices to mine cryptocurrency or spread malware.

Emerging Security Solutions

A. Zero Trust and Blockchain Integration

- **Zero Trust Architecture (ZTA):** “Never trust, always verify” approach for access control.
- **Blockchain:** Ensures decentralized authentication, immutable audit trails, and secure transaction records.
- Combination mitigates risks from both insider and external threats.

B. AI and Machine Learning Defenses

- **Machine Learning Models:** Detect anomalous transaction patterns, prevent account takeovers, and identify deepfake attempts.
- **GAN-based fraud detection:** Helps identify AI-generated synthetic identities.
- **Adaptive AI systems:** Learn from evolving attack patterns for proactive defense.

C. Biometric and Multi-Factor Authentication

- Biometric modalities (fingerprint, facial, voice recognition) enhance authentication security.
- Multi-Factor Authentication (MFA) reduces risk of account compromise.
- Risk-based adaptive authentication evaluates context, location, and behavior before granting access.

D. Quantum-Resistant Cryptography

- Quantum computing threatens traditional cryptographic algorithms.
- Financial platforms need to adopt quantum-resistant cryptography for long-term data protection.

E. Regulatory and Compliance Enhancements

- Financial regulators such as RBI, EU PSD2, and others mandate:
  - Risk-based authentication
  - Real-time transaction monitoring
  - Automated reporting and auditing
- Compliance frameworks ensure operational security while reducing legal and financial exposure.

F. Additional Security Solutions

- **Continuous Threat Intelligence:** Integration of global threat feeds into security operations.
- **Endpoint Detection and Response (EDR):** Monitors and mitigates device-level threats in real time.
- **Security Orchestration, Automation, and Response (SOAR):** Automates incident response workflows.
- **Cloud Security Posture Management (CSPM):** Secures cloud-based FinTech and e-commerce environments.

Conclusion

The cybersecurity landscape in FinTech payments and e-commerce is rapidly evolving. AI-driven attacks, ransomware, supply chain vulnerabilities, and identity-based threats highlight the need for adaptive, multi-layered defense architectures. Effective protection requires:

- Zero Trust frameworks and blockchain integration,
- AI-based monitoring and anomaly detection,
- Quantum-safe cryptography, and
- Compliance-driven security operations.

Future research should focus on adaptive AI defense models, quantum-resistant algorithms, cross-platform security orchestration, and proactive supply chain risk management to counter emerging threats. Financial institutions and e-commerce platforms must embrace these strategies to secure modern digital financial ecosystems.

References

1. A. Singh, V. Pareek, and A. Sharma, "Blockchain-Enabled Zero Trust Framework for Securing FinTech Ecosystems,"
2. D. Javaheri, M. Fahmideh, et al., "Cybersecurity Threats in FinTech: A Systematic Review,"
3. K. Zong, S. Zhou, et al., "Detection of AI Deepfake and Fraud in Online Payments Using GAN-Based Models,"
4. Reserve Bank of India, "Digital Payment Guidelines," 2025.
5. Visa, "6 Security Trends Shaping the Payments Ecosystem," 2026.

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Original Article

AI-Powered Transformation: Revolutionizing Industry, Education and Research

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Abstract

Artificial Intelligence (AI) is fundamentally reshaping contemporary society by transforming industry, education, and scientific research. Across industries, AI-driven technologies such as machine learning, predictive analytics, robotics, and generative systems are enhancing productivity, optimizing supply chains, enabling personalized customer experiences, and accelerating innovation. From smart manufacturing and precision agriculture to fintech automation and healthcare diagnostics, AI is redefining operational efficiency and competitive advantage in the digital economy.

In education, AI-powered tools are enabling adaptive learning environments, intelligent tutoring systems, automated assessment, and data-driven academic decision-making. These technologies support personalized learning pathways, expand access to quality education, and assist educators in curriculum design and student performance analysis. At the same time, generative AI systems are reshaping pedagogical practices, raising new considerations around academic integrity, digital literacy, and equitable access. In research, AI accelerates knowledge discovery by analyzing large datasets, modeling complex systems, supporting simulations, and assisting in hypothesis generation. From drug discovery and climate modeling to social science analytics, AI enhances research efficiency, interdisciplinary collaboration, and evidence-based policymaking.

***Keywords**: AI Integration, Industry Efficiency, Education Personalization, Research Discovery, Ethics in AI, Accessibility, Human-AI Collaboration, Bias Mitigation, Dependency Concerns, Interdisciplinary Approaches, Equitable AI Benefits.*

Introduction

Artificial Intelligence (AI) has emerged as a transformative force across various sectors, reshaping how we work, learn, and discover. In industry, AI drives efficiency, innovation, and competitive advantage by automating processes and enabling data-driven decisions. In education, it personalizes learning experiences, making knowledge more accessible and tailored to individual needs. In research, AI accelerates discoveries, handles complex data analysis, and fosters interdisciplinary collaborations. As of 2025, the integration of AI in these areas is not just a trend but a necessity, with projections indicating that 97 million people will work in AI-related roles by the end of the year. This chapter explores the applications, benefits, challenges, and future implications of AI in industry, education, and research, drawing on recent developments and expert insights.

AI in Industry

In the industrial sector, AI is revolutionizing operations by optimizing supply chains, predicting maintenance needs, and enhancing product development. Key trends for 2025 include multimodal AI, AI agents, and AI-powered search, which are enabling organizations to capitalize on data in unprecedented ways. For instance, in manufacturing, AI-driven predictive analytics can reduce downtime by up to 50% through real-time equipment monitoring. In finance, AI algorithms detect fraud with higher accuracy, processing vast datasets that humans cannot manage efficiently.

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Healthcare benefits from AI in diagnostics and personalized medicine, where machine learning models analyze medical images to identify diseases early. In robotics, AI enables autonomous systems that perform complex tasks in hazardous environments, improving safety and efficiency. Natural Language Processing (NLP) is another critical application, powering chatbots and virtual assistants that streamline customer service across industries.

AI in Education:

AI is transforming education by making it more inclusive, personalized, and efficient. In 2025, tools like adaptive learning platforms adjust content in real-time based on student performance, boosting engagement and outcomes. For example, AI-powered tutors provide instant feedback, helping students in subjects like math and languages without waiting for teacher intervention.

Major organizations, including Microsoft, are committing to AI education initiatives, reaching over 1 million students with AI-enabled resources by fall 2025. UNESCO's Digital Learning Week 2025 emphasizes human-centered AI to ensure equitable access. The U.S. Department of Education has issued guidance on responsible AI use in schools, outlining principles for functions like grading and content creation.

However, concerns persist about over-reliance on AI, potentially stifling critical thinking. Conferences like the AI and the Future of Education 2025 discuss innovations and ethical integration. Microsoft's special report notes AI's role in inclusion, such as assisting students with disabilities through voice-to-text and predictive typing.

AI in Research

In research and academia, AI is accelerating innovation by automating data analysis, simulating experiments, and generating hypotheses. Industry dominates AI model development, but academia leads in highly cited papers, as per the 2025 AI Index Report. Significant investments in R&D highlight industry's role, while academia focuses on foundational advancements.

AI enhances academic writing through idea generation, literature synthesis, and ethical compliance checks. In fields like biology and physics, AI tools analyze genomic data or model climate scenarios faster than traditional methods. However, growing dependency raises concerns about creativity and integrity. The AAAI report on the Future of AI Research notes a shift toward corporate environments due to resource availability. Substack discussions from early 2025 cover higher education's engagement with AI, including policy adaptations. The AAUP warns of threats to academic professions from uncritical AI adoption, such as job losses.

AI Technologies in Censorship and Moderation

Modern censorship and content moderation procedures in films, TV shows, and online media now heavily rely on artificial intelligence technologies. Manual moderation is no longer feasible due to the proliferation of streaming services and user-generated video content. Rather, computer vision, natural language processing (NLP), and audio analysis-driven AI systems are now essential for detecting, categorising, and controlling sensitive or offensive content (Gillespie, 2018). Global streaming behemoths like Netflix, Amazon Prime, and YouTube, as well as regional platforms in Asia and Europe, are embracing these technologies at an increasing rate.

1. Computer Vision:

Large datasets are used to train computer vision algorithms, which are especially good at identifying visual components in movies. Convolutional Neural Networks (CNNs) are highly accurate at detecting weapons, excessive violence, drug use, and nudity on screen (Redi et al., 2021). AI-based moderation tools, for example, can automatically flag explicit content or blur offensive scenes prior to distribution. Another new application that is particularly pertinent to stopping manipulated videos from misleading viewers or enabling actors to perform without permission is deepfake detection (Mirsky & Lee, 2021). These systems are used for automated age-rating assignments in addition to censorship, making sure that visual cues match regulatory classifications like PG-13 or 18+.

2. Natural Language Processing (NLP):

Film censorship heavily relies on language, and both dialogue and scripts are screened using natural language processing (NLP) tools. AI can identify hate speech, profanity, and politically sensitive terms in a variety of languages by examining closed captions and subtitles (Fortuna & Nunes, 2018). AI can contextualise whether terms are used in a humorous, aggressive, or disparaging manner thanks to sentiment analysis. Through the identification of culturally inappropriate expressions, NLP helps ensure compliance with regional censorship laws in multilingual contexts. Moreover, streaming platforms use natural language processing (NLP) models for predictive moderation, automatically examining uploaded scripts or transcriptions to anticipate possible regulatory problems prior to production (Kumar et al., 2022).

3. Audio Analysis:

By directly examining dialogue and soundtracks, audio-based AI models go beyond textual transcripts in moderation. These devices can mute movie scenes, identify offensive language, and recommend automated bleeping (Schmidt & Wiegand, 2017). Additionally, audio analysis can detect emotionally charged sound patterns that are associated with violent or upsetting scenes, such as screams or aggressive tones. Platforms can record instances that purely text-based or visual systems might miss thanks to this multimodal approach.

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4. **Multimodal AI Systems:**

The most sophisticated censorship technologies are multimodal systems that integrate audio analysis, computer vision, and natural language processing. These systems offer a more comprehensive evaluation of movie content by combining several data streams (Baltrušaitis, Ahuja, & Morency, 2019). For instance, YouTube's Content ID system simultaneously scans audio, video, and metadata using multimodal AI to identify objectionable content and copyright violations. Like this, TikTok uses multimodal moderation to swiftly identify offensive speech, inappropriate music, and nudity in short-form videos. Such systems are used in the film industry to make sure that the narrative and visual elements of films are assessed considering various cultural sensitivities.

Applications of AI in Film Censorship

Worldwide, the use of artificial intelligence (AI) in the processes of content moderation and movie censorship is growing. The sheer volume and diversity of media have become too much for traditional manual censorship to handle with the explosive growth of digital streaming services and user-generated content platforms. Artificial intelligence (AI) technologies offer scalable and effective solutions for monitoring, filtering, and classifying motion picture content by fusing computer vision, natural language processing (NLP), and machine learning.

1. **Pre-Release Screening:**

Before submitting their films to censorship boards, film production companies are using AI systems to perform preliminary scans. These systems have the ability to automatically detect content that might be in violation of regional laws, including hate speech, graphic violence, nudity, and politically sensitive symbols (Sharma & Banerjee, 2022). AI-based content analysis tools, for instance, can identify and blur restricted images or highlight particular scenes for human review, which lessens the workload for censors while maintaining compliance.

2. **Streaming Platforms and Automated Flagging:**

AI is used by major over-the-top (OTT) services like Netflix, Amazon Prime, and Disney+ to classify and filter content on a large scale. AI systems categorise films based on age ratings (PG, R, 18+, etc.) and issue warnings about drug use, violence, or sexual content (Zhou & Li, 2021). In addition to assisting regulators, these resources enable viewers—especially parents—to make knowledgeable viewing decisions. Additionally, by customising classifications for various geographical areas, machine learningbased moderation enables platforms to localise censorship standards.

3. **Social Media and Short Film Distribution**:

AI is now essential to real-time moderation due to the proliferation of short-form content on YouTube, Instagram, and TikTok. For example, YouTube's Content ID system employs AI to scan millions of videos every day, detecting explicit or harmful content and flagging copyright violations (Gillespie, 2018). Similarly, TikTok enforces censorship policies globally by using AI-driven systems that automatically remove, or shadow-ban videos judged unsuitable for audiences.

4. **Automated Age Ratings and Parental Controls:**

The way films are rated is also being changed by AI systems. Algorithms trained on large datasets of rated films can automatically assign age classifications, eliminating the need for human committees (Kim, 2020). These systems generate nuanced ratings by analysing tone and thematic components in addition to language and images. With the help of these ratings and parental control tools, AI filters can either block or suggest content according to a child's viewing preferences and history.

5. **Regional Sensitivities and Cultural Adaptation**:

Platforms can implement region-specific censorship thanks to AI's flexibility. For example, in countries with restrictive regulations, AI moderation tools can be set up to flag or remove LGBTQ+ content, even though LGBTQ+ representation is normalised in Western markets (Shen, 2021). This ability to customise censorship illustrates AI's dual function of facilitating worldwide distribution while also enforcing regional political and cultural borders. AI has a wide range of uses in film censorship, from automated age ratings and prerelease compliance checks to real-time content moderation on social media and streaming services. These technologies improve consistency and efficiency, but they also bring up issues of artistic freedom and cultural relativism, which are covered in more detail in later sections.

Advantages of AI in Film Moderation

The film industry, regulatory agencies, and viewers can all benefit greatly from the use of artificial intelligence (AI) in film moderation. Artificial intelligence (AI) systems can handle enormous volumes of textual and visual content in ways that human censors cannot match in terms of scale and speed by utilising machine learning, computer vision, and natural language processing (NLP).

1. **Speed and Scalability:**

The capacity of AI to swiftly process vast amounts of content is one of its most important benefits for movie moderation. The exponential growth of films and digital content released on various platforms presents difficulties for traditional censorship boards that rely on manual review. Streaming services like Netflix, Amazon Prime, and YouTube can show thousands of films and videos every day because AI-based systems can analyse hours of footage in a matter

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of minutes (Gillespie, 2018). Real-time content moderation is made possible by this scalability, which is especially important for platforms that manage user-generated content.

2. Consistency in Decision-Making:

Cultural, political, or personal biases are frequently introduced into the decision-making process by human moderators and censorship boards. This leads to disparities in evaluations between various films or geographical areas. However, to ensure consistency in the application of moderation rules, AI systems rely on predefined datasets and algorithms to flag content (Kumar, 2021). For instance, pattern-recognition models reliably detect violence or nudity in films, irrespective of the reviewer. Consistency like this lessens subjectivity and increases the predictability of censorship decisions.

3. Cost-Effectiveness:

The financial and human resources needed for movie censorship are greatly decreased by the application of AI. For manual screening, hiring sizable reviewer teams is costly and time-consuming. By offering first-level moderation, automated tools reduce these expenses and free up human reviewers to concentrate solely on edge cases or culturally sensitive issues (Chen, 2020). For production companies and streaming services, this hybrid model of AIassisted censorship maximises efficiency and cost.

4. Adaptability and Learning:

By using updated datasets for training, AI systems can adjust to changing standards and guidelines. Cultural sensitivities regarding political representation, gender, and religion, for example, change over time. It is possible to retrain AI-driven models, especially those built on deep learning, to identify novel symbols, languages, or expressions that might need to be moderated (Shahid, 2022). This flexibility guarantees that censorship techniques continue to be applicable in quickly shifting political and cultural environments.

5. Enhanced Audience Protection:

Additionally, AI-based moderation is crucial for safeguarding viewers, particularly young people and other vulnerable populations. Automated age-rating systems can help parents control their children's viewing choices by categorising content according to sexual content, violence, or explicit language (Livingstone & Byrne, 2018). Additionally, viewing filters that can be customised are made possible by AI-driven parental

6. Support for Global Distribution:

AI assists in identifying region-specific issues as films and television shows are distributed internationally, guaranteeing adherence to regional regulatory standards. For instance, a movie that is deemed appropriate in the US might be criticised for its religious overtones in India or its political sensitivity in China. Smoother worldwide distribution can be achieved by training AI-based moderation tools to identify and modify content for various cultural markets (Napoli, 2019). AI improves the film moderation process by increasing efficiency, lowering costs, and ensuring consistency. It is an essential tool in the digital age because of its capacity to manage enormous volumes of content, adjust to cultural shifts, and improve audience protection. Even though these benefits are clear, maintaining artistic freedom and contextual awareness requires striking a balance between automation and human oversight.

Limitations and Challenges

There are still several restrictions and difficulties even with the increasing use of AI in content moderation and movie censorship.

1. Technical Limitations:

It can be challenging for AI-driven moderation systems to reliably identify sensitive content. Innocent artistic expressions are frequently marked as inappropriate, a phenomenon known as false positives. Scenes showing historical conflicts or medical procedures, for instance, could be mistakenly classified as violent or graphic (Gillespie, 2018). In a similar vein, algorithms may miss subtle political or cultural references, leading to false negatives that cast doubt on their dependability (Roberts, 2019). Due to their heavy reliance on training datasets, AI systems' accuracy is limited by the quantity and calibre of data at their disposal.

2. Algorithmic Bias:

The objectivity of AI systems depends on the quality of the data they are trained on. Films made in non-Western contexts might be misunderstood or disproportionately censored if the training data primarily represents Western cultural norms (Noble, 2018). For instance, just because the system doesn't make enough cultural references, representations of traditional clothing, religious rituals, or regional idioms might be marked as odd or offensive. As a result, censorship rules are applied unevenly, and digital colonialism in international film distribution may continue.

3. Cultural and Political Sensitivities:

Censorship is never culturally neutral. The boundaries of what is deemed acceptable vary among societies. For example, LGBTQ+ themes may be censored in nations with conservative cultural or religious values but normalised in Western cinema (Li, 2020). These localised sensitivities are difficult for AI systems built for global operations to adjust to, which frequently results in either excessive or insufficient censorship. Concerns regarding authoritarian control over film are also raised by the possibility that governments will use AI moderation tools to stifle political criticism or politically delicate stories.

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4. Impact on Artistic Freedom:

The impact of AI censorship on artistic freedom is arguably the biggest obstacle. Filmmakers may practise proactive self-censorship by steering clear of contentious subjects out of concern that they will be flagged by algorithms. The cultural and political function of film as a platform for critical expression may be diminished by such creative limitations (Zeng, 2021). Furthermore, AI is unable to comprehend subtlety, satire, or symbolic narrative—all of which are critical components of film as an art form. The intricacy and depth of cinematic narratives could be compromised by the automated filtering of content. Even though AI makes content moderation more efficient and scalable, there are still a lot of obstacles because of its ethical, political, cultural, and technical limitations. To protect both regulatory goals and creative freedoms, a balanced strategy combining AI tools with human oversight is necessary. Case Studies: These case studies highlight the variou

Conclusion:

AI's integration into industry, education, and research is poised to drive unprecedented progress in 2025 and beyond. While industry leverages AI for efficiency, education uses it for personalization, and research for discovery, common themes of ethics, accessibility, and humanAI collaboration emerge. Addressing challenges like bias and dependency will ensure AI benefits society equitably. As AI evolves, interdisciplinary approaches will be key to harnessing its full potential.

References:

1. McKinsey & Company. (2025). The State of AI: Global survey. Retrieved from https://www.mckinsey.com/capabilities/quantumblack/our-insights/the-state-of-ai
2. Stanford HAI. (2025). The 2025 AI Index Report. Retrieved from https://hai.stanford.edu/ai-index/2025-ai-index-report
3. Exploding Topics. (2025). 50 NEW Artificial Intelligence Statistics (July 2025). Retrieved from https://explodingtopics.com/blog/ai-statistics
4. Morgan Stanley. (2025). 5 AI Trends Shaping Innovation and ROI in 2025. Retrieved from https://www.morganstanley.com/insights/articles/ai-trends-reasoning-frontier-models2025-tmt
5. PwC. (2025). The Fearless Future: 2025 Global AI Jobs Barometer. Retrieved from https://www.pwc.com/gx/en/issues/artificial-intelligence/ai-jobs-barometer.html
6. NetCom Learning. (2025). Top 10 Applications of Artificial Intelligence (AI) in 2025. Retrieved from https://www.netcomlearning.com/blog/applications-of-ai
7. McKinsey & Company. (2025). McKinsey technology trends outlook 2025. Retrieved from https://www.mckinsey.com/capabilities/mckinsey-digital/our-insights/the-top-trendsin-tech

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Original Article

A Review Study of Mimic Molecules of Heme Moiety

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Abstract

Heme (Hb) is an essential iron–porphyrin complex that plays a critical role in biological systems, including oxygen transport, electron transfer, catalysis, and redox reactions. Due to its importance in hemoglobin, myoglobin, cytochromes, peroxidases, and catalases, significant efforts have been made to design and synthesize heme mimic molecules. These biomimetic systems help in understanding structure–function relationships and have applications in catalysis, medicine, and material science. This review discusses the structural features of heme, various synthetic heme mimics, their coordination chemistry, catalytic properties, and emerging applications.

Keywords: *mimic molecules, metal complexes, application of metal complexes.*

Introduction

Heme consists of an iron ion (Fe^{2+}/Fe^{3+}) coordinated to a porphyrin ring (protoporphyrin IX). It functions as: Oxygen carrier (Hemoglobin, Myoglobin) Electron transfer agent (Cytochromes) Oxidation catalyst (Peroxidases, Catalases) Gas sensor (NO, CO binding proteins) However, natural heme proteins are complex and unstable outside biological environments. Therefore, synthetic heme mimics are developed to: Understand biological mechanisms, Model enzymatic activity, develop artificial catalysts, Create therapeutic agents.

Medicinal applications of metals have played an important role in medicine for thousands of years. Many essential metal ions in our diets in varying quantities are essential, although its significance has been recently realized, which could probably be attributed to our increased awareness of personnel and families' health. Metal complexes or coordination complexes, is an atom or ion (usually metallic), bonded to a surrounding array of molecules or anions, which are in turn known as ligands or complexing agents. Virtually all compounds containing metals consist of coordination complexes. Coordination first to the "coordinate covalent bonds" (dipolar bonds) between the ligands and central atom. Originally complex implied a reversible association of molecules, atoms or ions through such weak chemical bonds. As applied to coordination chemistry this meaning has evolved some metal complexes are formed virtually irreversibly and many are bound together by bonds that are quite strong. Metal complexes with labile ligands have long been known to undergo ligand substitution reactions with biomolecular targets. Metal ions can bind to nitrogen, sulfur or selenium atoms of the histidine, cysteine, or selenocysteine residues in proteins leading to therapeutics effects.3 Metal complexes are so pervasive that the structure and reaction are described in many ways, sometime confusingly. The atom within a ligand that is bonded to the central atom or ion is called the donor atom. A typical complex is bound to several donor atoms, which can be different or same. Ligand based classification of metal complexes The majority of ligands are anions or neutral molecules that function as electronpair donors (Lewis's base)

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Structural Features of Heme

Central iron ion (Fe^{2+} or Fe^{3+}) Tetrapyrrolic porphyrin macrocycle Four nitrogen donors in square planar arrangement One or two axial ligands (e.g., histidine, O_2, CO, CN^-) The coordination environment strongly influences: Redox potential, Spin state, Reactivity Ligand binding affinity.

Types of Heme Mimic Molecules

Metalloporphyrins

Synthetic iron porphyrins are the closest structural mimics of heme.

Examples:

Iron (III) tetraphenyl porphyrin (FeTPP) Iron octaethylporphyrin (FeOEP)

Applications: Oxidation catalysis (alkene epoxidation, hydroxylation) Oxygen reduction reactions
Study of spin-state transitions

Advantages:

High structural similarity, Tunable substituents

Limitations:

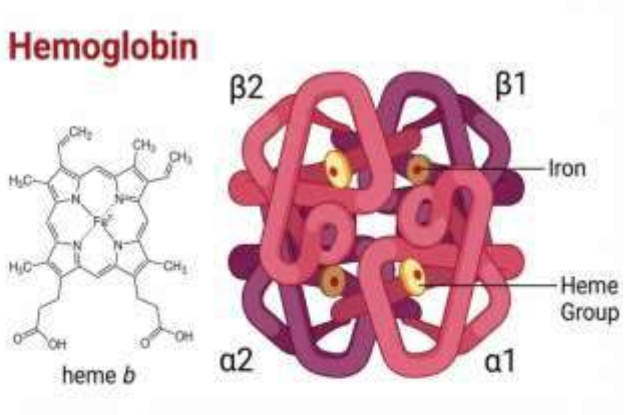
Susceptible to oxidative degradation.

Corroles and Phthalocyanines

These are porphyrin analogues with modified macrocycles. Corroles: Contracted porphyrins (stronger ligand field) Phthalocyanines: Extended conjugation systems

Applications:

Catalysis, Photodynamic therapy, Artificial photosynthesis



Schiff Base Iron Complexes

Iron complexes with tetradentate Schiff base ligands (e.g., salen-type ligands) mimic heme coordination.

Applications:

Biomimetic oxidation reactions, Peroxidase-like activity

Advantages:

Easier synthesis, Structural flexibility.

Metal–Organic Framework (MOF)-Based Heme Mimics

Iron-porphyrin units incorporated into MOFs.

Applications:

Heterogeneous catalysis, Gas storage and sensing, Electrochemical reactions

Advantages:

High surface area, Recyclability.

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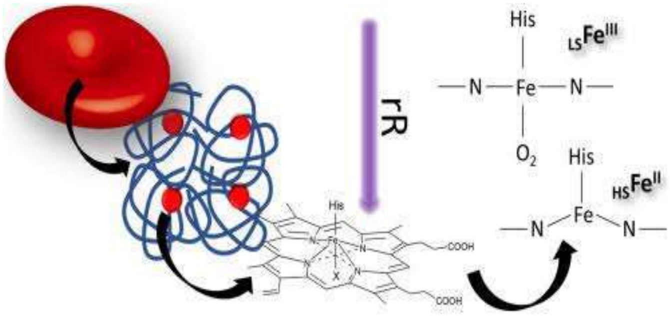
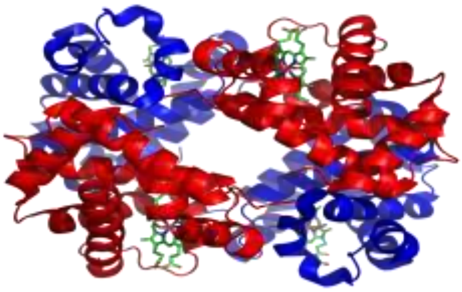
Nanomaterial-Based Heme Mimics
Iron oxide nanoparticles and nanozymes exhibit peroxidase-like activity.
Applications:
Biosensing, Cancer therapy, Environmental remediation.

Functional Properties of Heme Mimics
Oxygen Binding and Transport
Some synthetic iron porphyrins reversibly bind O_2 under controlled conditions, helping to understand hemoglobin behavior.



Catalytic Oxidation
Heme mimics are widely used for: Hydroxylation of hydrocarbons, Epoxidation of alkenes Degradation of pollutants, they simulate cytochrome P450 enzyme activity.

Electron Transfer Reactions
Used in: Fuel cells (O_2 reduction reaction), Electrochemical sensors, Artificial photosynthetic systems.



Applications
+ Biomedical Field
+ Artificial blood substitutes
+ Drug delivery systems
+ Cancer phototherapy
+ Industrial Catalysis
+ Green oxidation processes
+ Fine chemical synthesis
+ Environmental Chemistry
+ Degradation of dyes
+ Water purification
+ Energy Research
+ Fuel cells
+ CO_2 reduction

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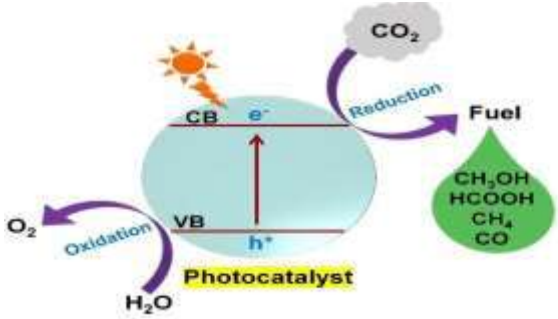

Challenges and Future Perspectives
Challenges:
- Stability under oxidative conditions
- Controlling selectivity
- Preventing catalyst degradation
- Mimicking protein microenvironment
- Future directions:
- Designing second-sphere interactions
- Hybrid bio–synthetic systems
- Immobilized catalytic platforms
- Computational design of biomimetics

Conclusion

Heme mimic molecules have significantly contributed to understanding biological redox processes and developing efficient catalytic systems. Metalloporphyrins remain the most structurally relevant mimics, while nanozymes and MOF-based systems offer promising industrial applications. Continued advancements in ligand design and material integration will enhance their efficiency and practical utility.

References
1. Dolphin, D. The Porphyrins; Academic Press: New York.
2. Collman, J. P.; Boulatov, R. Functional Models of Cytochrome P450.
3. Groves, J. T. High-valent iron intermediates in oxidation catalysis.
4. Meunier, B. Metalloporphyrins as biomimetic catalysts.
5. Breslow, R. Artificial enzyme systems.
6. Que, L.; Tolman, W. B. Biologically inspired oxidation catalysis.
7. Suslick, K. S. Metalloporphyrin materials chemistry.
8. Gao, L. et al. Intrinsic peroxidase-like activity of ferromagnetic nanoparticles.

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Original Article

Impact of Cybersecurity on E-Commerce in India

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Abstract

As India's e-commerce market scales toward a $300 billion valuation, it has become a primary target for sophisticated cyber threats, including AI-driven fraud and ransomware. This paper examines the multifaceted impact of cybersecurity on the Indian digital trade landscape, focusing on financial erosion, consumer trust, and the legislative shift brought by the Digital Personal Data Protection (DPDP) Act, 2023. Statistical analysis reveals that the average cost of a data breach in India has reached a record ₹22 crore ($2.6 million), with malicious bots now accounting for nearly 70% of e-commerce traffic. Through a review of current threat vectors—specifically UPI-based fraud and supply chain vulnerabilities—the study identifies that the "fear of cybercrime" acts as a significant barrier to digital adoption. The paper concludes that for Indian e-commerce to sustain its growth trajectory, businesses must transition from reactive security to a Zero Trust Architecture and AI-powered proactive defence. This research provides a strategic framework for stakeholders to mitigate risks while navigating India's evolving regulatory and technological environment.

Keywords: *Cyber Security, E-Commerce, India.*

Introduction

India highlights that cyber security sector drives massive economic growth, it faces an escalating "arms race" between sophisticated cybercriminals and defensive technologies. the impact of cybersecurity on e-commerce in India underscores a dual reality: while digital trade is projected to reach $100 billion by 2025, it faces a parallel surge in sophisticated cyber threats that directly erode this growth. In 2025-2026, the impact of cybersecurity on e-commerce in India has shifted from a technical background concern to a central driver of business performance and national economic policy. As the market heads toward an estimated $145–$160 billion GMV in 2025, it faces a parallel rise in sophisticated, industrialised cybercrime.

Objectives of the study:

- To understand the concept of cyber security and e-commerce.
- To know the impact of cyber security on e-commerce.
- To highlight the issues of cyber security on e-commerce.
- To analyse the strategies to overcome from issues.

Research methodology:

This research paper is completely based on secondary data. The required information is collected from the various journals, websites and reports.

Types of cybersecurity

Many types of cybersecurity are employed to protect digital systems from malicious and accidental threats. It is helpful to understand the ten most commonly referenced types of cybersecurity.

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- **Application Security**
  Application security prevents unauthorized access and use of applications and connected data. Because most vulnerabilities are introduced during the development and publishing stages, application security includes many types of cybersecurity solutions to help identify flaws during the design and development phases that could be exploited and alert teams so they can be fixed. Despite best efforts, flaws do slip through the cracks. Application security also helps protect against these vulnerabilities. A subset of application security is web application security. It focuses on protecting web applications, which are frequently targeted by cyber-attacks.
- **Cloud Security**
  Cloud security focuses on protecting cloud-based assets and services, including applications, data, and infrastructure. Most cloud security is managed as a shared responsibility between organizations and cloud service providers. In this shared responsibility model, cloud service providers handle security for the cloud environment, and organizations secure what is in the cloud. Generally, the responsibilities are divided as shown below.
- **Critical Infrastructure Security**
  Special security processes and types of cybersecurity solutions are used to protect the networks, applications, systems, and digital assets depended on by critical infrastructure organizations (e.g., communications, dams, energy, public sector, and transportation). Critical infrastructure has been more vulnerable to cyber-attacks that target legacy systems, such as SCADA (supervisory control and data acquisition) systems. While critical infrastructure organizations use many of the same types of cybersecurity as other subcategories, it is often deployed in different ways.
- **Data Security**
  A subset of information security, data security combines many types of cybersecurity solutions to protect the confidentiality, integrity, and availability of digital assets at rest (i.e., while being stored) and in motion (i.e., while being transmitted).
- **Endpoint Security**
  Desktops, laptops, mobile devices, servers, and other endpoints are the most common entry point for cyber-attacks. Endpoint security protects these devices and the data they house. It also encompasses other types of cybersecurity that are used to protect networks from cyber-attacks that use endpoints as the point of entry.
- **IoT (Internet-of-Things) Security**
  IoT security seeks to minimize the vulnerabilities that these proliferating devices bring to organizations. It uses different types of cybersecurity to detect and classify them, segment them to limit network exposure, and seek to mitigate threats related to unpatched firmware and other related flaws.
- **Mobile Security**
  Mobile security encompasses types of cybersecurity used to protect mobile devices (e.g., phones, tablets, and laptops) from unauthorized access and becoming an attack vector used to get into and move networks.
- **Network Security**
  Network security includes software and hardware solutions that protect against incidents that result in unauthorized access or service disruption. This includes monitoring and responding to risks that impact network software (e.g., operating systems and protocols) and hardware (e.g., servers, clients, hubs, switches, bridges, peers, and connecting devices). The majority of cyber-attacks start over a network. Network cybersecurity is designed to monitor, detect, and respond to network-focused threats.
- **Operational Security**
  Operational security covers many types of cybersecurity processes and technology used to protect sensitive systems and data by establishing protocols for access and monitoring to detect unusual behaviour that could be a sign of malicious activity.
- **Zero-trust**
  The zero trust security model replaces the traditional perimeter-focused approach of building walls around an organization's critical assets and systems. There are several defining characteristics of the zero-trust approach, which leverages many types of cybersecurity.

E-commerce

At its core, e-commerce involves conducting commercial transactions online, ranging from the sale of physical goods to digital products and services. It also includes electronic processes such as online banking, subscription services, and digital content distribution. Modern e-commerce platforms are designed to provide a seamless experience for users by offering product catalogues, secure payment gateways, customer support, and delivery options. The ability to conduct business digitally allows companies to reach global markets, cater to diverse customer needs, and operate more efficiently than traditional brick-and-mortar stores. Additionally, e-commerce enables businesses to collect valuable customer data, track shopping behaviour, and personalize marketing campaigns to improve engagement and sales.

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Types of E-Commerce:
E-commerce business models can generally be divided into the following categories.
• Business - to - Business (B2B)
• Business - to - Consumer (B2C)
• Consumer - to - Consumer (C2C)
• Consumer - to - Business (C2B)
• Business - to - Government (B2G)
• Government - to - Business (G2B)
• Government - to - Citizen (G2C)

Online stores like Amazon, Walmart, AJIO, Flipkart, Shopify, Myntra, Zara, Quikr, Blinkit,Olx are examples of Ecommerce websites.

History of E-commerce

1960s – The Origins	• Electronic Data Interchange (EDI) developed to exchange business documents electronically. • Used by companies to transfer invoices, purchase orders, and shipping notices
1970s – Early Online Transactions	1979: British inventor Michael Aldrich develops online shopping using a modified TV and phone line—considered the birth of e-commerce. • Used primarily for B2B transactions.
1980s – Expansion of EDI and B2B	Widespread adoption of EDI in industries like manufacturing and retail. • Limited consumer access to online platforms
1990s – The Internet Revolution	• 1991: The Internet becomes publicly accessible. • 1994: Netscape Navigator, a major web browser, launches. • 1995: o Amazon and eBay launch, revolutionizing online retail. o SSL encryption introduced for secure online transactions.
2000s – Growth and Trust	E-commerce becomes main stream. • Online banking, payment gateways (like PayPal), and retail giants expand. • Rise of B2C platforms and global marketplaces. • E-commerce regulations and fraud protection develop

Impact of cybersecurity on E-Commerce
Economic & Financial Impact
- **Direct Losses:** Indian entities are projected to lose approximately ₹20,000 crore (~$2.4 billion) to cybercrime in 2025 alone. Of this, e-commerce and retail are expected to bear a massive brunt of around **₹**5,800 crore.
- **Surging Breach Costs:** The average cost of a data breach in India has hit a record ₹22 crore ($2.6 million) in 2025, making India one of the most expensive regions for cyber incidents globally.
- **Ransomware Disruption:** Ransomware remains the most destructive threat, with some Indian states reporting over 17,000 cases in 2025, leading to total operational shutdowns for many e-tailers.

Impact on Consumer Behaviour & Trust
- **Trust Deficit:** Research shows that **87% of consumers** would stop doing business with a company that fails to protect their data. In India, 36% of consumers now rank technology risks (cyberattacks/hacking) as a top-three threat to their daily life in 2025.
- **Visible Security as a Differentiator:** To maintain loyalty, Indian platforms are increasingly forced to implement visible security cues—such as 2FA, biometric authentication (fingerprint/facial recognition), and SSL encryption—which are now baseline expectations for 260+ million online shoppers.
- **Intangible Losses:** Beyond money, "intangible" losses—such as the permanent erosion of brand reputation—frequently lead to customers migrating to more secure competitors.

Emerging 2025-2026 Threat Landscape
- **AI-Enabled Fraud:** The rise of **Deepfake impersonation** and AI-powered phishing has automated the scale of attacks, making them nearly impossible to detect with traditional signature-based methods.
- **Bot-Heavy Traffic:** Malicious bots now account for over **50% of traffic** on many Indian e-commerce sites (e.g., reaching 7.25 billion out of 14.28 billion requests in late 2025), leading to inventory scalping and price scraping.

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- **Supply Chain Vulnerabilities:** Nearly **54% of Indian businesses** view supply chain disruptions from third-party vendors and exposed APIs as a primary concern for business continuity.

Strategic & Regulatory Responses

- **DPDP Act Compliance:** The Digital Personal Data Protection Act, 2023 mandates explicit consent and prompt breach notification, forcing e-commerce platforms to overhaul their data handling or face significant penalties.
- **Zero Trust Architecture:** There is a nationwide shift from "perimeter-based" defense to Zero Trust models, which follow the rule of "never trust, always verify" for every transaction.
- **Skill Gap:** Despite high investment, India faces a shortage of over 1 million cybersecurity professionals, which remains the biggest hurdle for e-commerce companies attempting to secure their digital infrastructure.

These market analyses and guides explore the economic impact, evolving threat landscape, and best practices for cybersecurity in India's e-commerce sector.

Issue Type	**Primary Impact in India**
Financial	Direct theft through UPI, digital arrest scams, and credit card skimming.
Operational	Ransomware causing multi-day shutdowns and supply chain paralysis.
Legal	Massive liability under DPDP Act for data leaks and consent failures.
Reputational	87% of consumers report they will stop buying from a brand after a data breach.

In 2025–2026, cybersecurity in Indian e-commerce has evolved into a critical business risk, where a single breach can threaten an organization's survival due to both technical complexity and stringent new legal penalties.

Strategy	**Action Step**
Identity Protection	Use biometric or app-based authenticators instead of SMS OTPs where possible.
Infrastructure	Implement Web Application Firewalls (WAF) and keep all software/plugins updated.
Data Privacy	Encrypt all sensitive data at rest and in transit using SSL/TLS protocols.
Monitoring	Enable 24/7 real-time monitoring of network traffic for rapid incident response.

Conclusion

The research confirms that the future of India’s e-commerce sector—projected to reach $300 billion by 2030—is fundamentally contingent on its cybersecurity resilience. The "industrialization" of cybercrime, now leveraging AI and deepfakes, has created an environment where a single breach can result not just in a record-high financial loss (averaging ₹22 crore), but in the permanent erosion of consumer trust. To sustain growth, Indian e-commerce platforms must transition toward a Zero Trust Architecture and invest heavily in Cyber-Hygiene Training. In an era where 60% of SMEs fail post-breach, the ability to protect data is no longer a "feature"—it is the ultimate competitive advantage in the Indian digital marketplace.

References:

1. 2025 Cost of a Data Breach Report: India Analysis
2. India Cyber Threat Report 2025.
3. Ministry of Electronics and Information Technology (MeitY) **(2023).** The Digital Personal Data Protection (DPDP) Act, 2023
4. cybercrime.gov.in
5. Annual Report 2024-2025. Indian Computer Emergency Response Team, Ministry of Electronics and Information Technology

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Original Article

Green Chemistry Principles and Applications

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Abstract

Green chemistry is a sustainable approach to chemical research and development that reduces or eliminate hazard substances. This paper highlights 12 principles of Green Chemistry including waste prevention, atom economy, safer chemicals and renewable feedstocks. These principles guide the design of eco-friendly products and processes, minimizing environmental impact and promoting human health.

Applications include sustainable synthesis, renewable energy, eco-friendly products and pharmaceuticals. Green Chemistry has led to biodegradable plastics, biofuels and energy-efficient processes. It promotes safer chemicals, reducing pollution and improving safety. The benefits of Green Chemistry include reduced environmental impact, improved safety, cost savings and sustainable development. Green Chemistry will drive innovation, reduce pollution and promote eco-friendly practices.

Introduction

With the growing awareness of environmental pollution, the international community is under increasing pressure to find methods to save our lives from the increasing pollution. The scientists are searching for new alternatives which do not cause environmental pollution. This new approach is called Green Chemistry which was introduced in the early 1990s. It means zero discharge of toxic, persistent substances into the environment guaranteed by the fact that they are never produced. Green chemistry is "a strategy to design chemical processes and products that reduces or eliminates the use and generation of hazardous substances."

This would bring about minimum pollution or deterioration to the environment. In other words, green chemistry aims to virtually eliminate toxic, persistent substances from the environment by insuring their no further releases and destroying existing deposits of these chemicals. So, Green Chemistry means environmentally friendly or no pollution. For example, we have been using organic solvents such as benzene, toluene, carbon tetrachloride etc. as a media for many reactions. These are highly toxic. Now, scientists are planning greener alternatives to use water or non-polluting solvents as a medium in place of organic solvents. Similarly, instead of using synthetic materials for packing, green chemistry plans to use environmentally friendly recyclable or safely disposable materials.

Basic aims of green chemistry

- Reformulation of synthetic routes so that hazardous substances do not enter into the atmosphere.
- During synthesis, care must be taken to select starting materials that can be converted into end products with almost 100% yield. This can be achieved by arriving at optimum conditions of synthesis.
- The methods used to obtain starting materials e.g. mining, refining etc. should have minimum impact on the natural environment.
- New routes for the production of green chemicals and materials.

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- The development of environmentally improved methods for the existing industrial processes. The material inputs should be of low or no toxicity or at least reduced toxicity compared with the traditional method.
- The use of starting materials-reagents and solvents that pose less hazard to man and his environment.
- The synthetic reactions may preferably be carried out in an aqueous medium because water has high specific heat and low volatility. Water is cost effective, non-inflammable and does not have any carcinogenic effects.
- The raw materials and methods should produce less waste to avoid their treatment and problem of disposal.
- The use of renewable rather than depleting resources wherever possible.
- The use of biotechnological alternatives.
- New methods and tools for evaluating environmental impact.
- The awareness among common man to use green products.

Principles of Green Chemistry with:

- **Prevention:** Prevent waste generation instead of treating it. This reduces environmental impact and saves costs. Effective prevention strategies are key to green chemistry.
- **Atom Economy:** Maximize atom efficiency in chemical synthesis. This means designing reactions where most atoms are incorporated into products. It reduces waste and improves efficiency.
- **Safer Chemicals:** Design chemicals that are safer for humans and the environment. This involves minimizing toxicity and environmental persistence. Safer chemicals reduce risks and pollution.
- **Safer Solvents:** Use safer solvents and auxiliaries in chemical processes. This reduces environmental and health risks. Water and ionic liquids are examples of safer alternatives.
- **Energy Efficiency:** Minimize energy requirements in chemical processes. This reduces greenhouse gas emissions and costs. Efficient processes are both eco-friendly and economical.
- **Renewable Feedstock's:** Use renewable raw materials instead of depleting resources. This promotes sustainability and reduces dependence on fossil fuels. Biomass and agricultural waste are examples.
- **Reduce Derivatives:** Minimize unnecessary derivatization steps in synthesis. This reduces waste and improves efficiency. Fewer steps mean fewer risks and less energy use.
- **Catalysis:** Use catalysts to improve reaction efficiency. Catalysts speed up reactions without being consumed. This reduces waste and energy use.
- **Design for Degradation:** Design chemicals to break down into harmless substances. This reduces environmental persistence and pollution. Biodegradable products are a good example.
- **Real-time Analysis:** Monitor chemical processes in real-time to prevent pollution. This allows for quick adjustments and reduces waste. Real-time analysis improves process control.
- **Inherently Safer Chemistry:** Design chemical processes to be inherently safer. This minimizes risks of accidents and exposure. Safer processes protect workers and the environment.
- **Accident Prevention:** Design processes to minimize accident risks. This involves considering potential hazards and mitigating them. Prevention is key to safety and sustainability.

Achievements of Green chemistry:

Since the inception of Green Chemistry, scientists from all over the world have used creative and innovative skills to develop new synthetic methods, new processes, analytical tools, reaction conditions, catalysts etc. So Green Chemistry prevents problems before they occur by designing new approaches. Green Chemistry considers the full life cycle impacts of a product at the initial design stage. A lot of success has been achieved in developing new techniques. Some of these are:

- Consider the production of adipic acid which is used for the manufacture of nylon 66. The most common process is petroleum derived benzene as the starting material. The last step for the synthesis of adipic acid requires oxidation by nitric acid resulting in nitrous oxide as a by-product. Nitrous oxide released in the atmosphere causes air pollution. Recent Green Chemistry research has developed a new method known as Draths-Frost synthesis of adipic acid. In this method adipic acid is obtained by genetically engineered microbe from glucose. This method prevents air pollution by nitrous oxide. Glucose has the further advantage of being a renewable feed stock and the process materials are of no toxicity.
- A new method for synthesizing ibuprofen in about 90% yield has been developed. This method avoids the use of large quantities of solvents and wastes associated with traditional stoichiometric use of auxiliary chemicals during chemical conversions.
- For the manufacture of polystyrene foam sheet packaging materials, the process of carbon dioxide as the blowing agent was developed. This method does not use conventional chloroflurocarbon blowing agents which contribute to ozone depletion, global warming and ground level smog.
- A new technique for catalytic hydrogenation of diethanolamine was developed. This method allows the production of environmentally friendly herbicide in a less dangerous way. This technology does not use cyanide and

formaldehyde and represents a major breakthrough in green chemistry. This technique is safer to operate, produces high overall yield and has less steps for the process.

- A safer marine antifouling compound 'sea-nine' was designed. It degrades far more rapidly than organotins which persist in the marine environment and cause pollution problems.

Green chemistry in day-to-day life:
Some common examples of green chemistry in our day-to-day life are:
Dry cleaning of clothes:
Tetrachloroethene ($Cl_2C=CCl_2$) has been used as solvent for dry cleaning. This compound is suspected to be carcinogenic and contaminates the groundwater. The process of using this compound has now been replaced by a new process in which liquefied carbon dioxide along with suitable detergent is used. This causes less harm to ground water. Replacement of halogenated solvent by liquid CO_2 will result in less harm to groundwater.
Similarly, hydrogen peroxide H_2O_2 is used for the purpose of bleaching clothes in the process of laundry. This gives better results and makes use of less water, therefore, saving a lot of water. It is also not harmful.
Bleaching of paper:
Chlorine gas was used earlier for bleaching paper which is a highly toxic chemical. Its use has been replaced by hydrogen peroxide with a suitable catalyst which promotes the bleaching action of hydrogen peroxide.
Synthesis of chemicals:
Ethanal (CH_3CHO) is commercially prepared nowadays by one step oxidation of ethene in the presence of ionic catalyst in aqueous medium:
$CH_2=CH_2 + O_2$------------- CH_3CHO (90%)
Ehene   Ethanal
The yield is about 90.0%
Thus, we can say that green chemistry is a cost-effective approach which involves reduction in material, energy consumption and waste generation.

Conclusion:
In conclusion Green Chemistry principles and applications offer a promising path towards a more sustainable future. By embracing the 12 principles we can reduce waste, conserve resources and create eco-friendly products. As industries adopt Green Chemistry we will see a shift towards cleaner processes, safer chemicals and reduced environmental impact. It's a win-win for our planet and future generation

References
1. Modern abc of Dr S P Jauhar.
2. Green chemistry: Environment friendly alternatives by Rashmi Sanghi and M M Srivastava.
3. Advances in Green Chemistry: Chemical synthesis using MW-irradiation by R S Varma.
4. Green Chemistry by Prof Dr K R Desai (2016)
5. Green Chemistry: Environmentally benign reactions by V K Ahluwalia (2022)
6. Green Chemistry by Dr. Rajnikanth Sharma, Dr. Sushila Singh, Dr. Monica Moond, Anuradha Beniwal, Jyoti Rani and Rajesh Moond (2023)

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Original Article

Digital Science for Climate Action and Planetary Health

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Abstract

The convergence of artificial intelligence (AI), geospatial analytics, and Earth observation technologies is catalyzing a transformative shift in how humanity confronts the dual crises of climate change and biodiversity loss. This chapter explores the role of digital science in advancing climate resilience and safeguarding planetary health. It presents AI-driven approaches for improving climate modeling and disaster forecasting, including the application of deep learning architectures such as LSTMs, CNNs, and GANs to enhance prediction accuracy, spatial resolution, and early warning capabilities. In the domain of biodiversity monitoring, the integration of drones, IoT devices, and computer vision algorithms enables real-time ecosystem surveillance, species identification, and ecological forecasting. The chapter also examines the rising field of GeoAI, which fuses AI with satellite remote sensing to deliver high-resolution environmental intelligence, from land cover classification to digital twins of Earth systems. Challenges related to data accessibility, model bias, ethical concerns, and computational sustainability are critically discussed. The chapter concludes with a future-oriented perspective emphasizing open science, ethical AI governance, indigenous knowledge integration, and emerging technologies such as quantum computing. Altogether, this work underscores the transformative power of digital science in shaping an equitable, data-informed, and sustainable trajectory for the Anthropocene. This chapter presents how digital science, particularly artificial intelligence (AI), geospatial technologies, and Earth observation systems are being used to support climate action and planetary health. Applications include climate modeling using AI for improved forecasts, disaster forecasting systems that integrate real-time data, and digital biodiversity monitoring through drones, sensors, and AI. GeoAI is revolutionizing Earth monitoring by enabling land cover mapping, carbon stock assessment, and vulnerability analyses. The chapter highlights challenges such as data accessibility and ethical concerns, and calls for equitable, transparent, and sustainable deployment of these technologies.

Keywords: *Digital Science; Climate Action; Planetary Health; Artificial Intelligence (AI); Machine Learning; Climate Modeling; Disaster Forecasting; Geoai; Earth Observation; Remote Sensing; Biodiversity Monitoring; Ecological Forecasting; Digital Twins; Environmental Informatics; Citizen Science; Iot; Deep Learning; Conservation Technology; Sustainability Analytics*

Introduction

The accelerating pace of climate change and its cascading impacts on ecosystems, economies, and human health demand innovative and integrative solutions. Digital science, characterized by the convergence of big data analytics, artificial intelligence (AI), remote sensing, and geospatial technologies, is rapidly emerging as a critical enabler for climate resilience and planetary health. From predictive climate modeling to real-time biodiversity monitoring, digital science tools are revolutionizing how we understand, monitor, and respond to complex environmental challenges. This chapter explores how digital technologies, particularly AI and GeoAI, are being deployed to support climate action, disaster forecasting, and the stewardship of planetary health. Environmental sustainability and ecological balance are interdependent concepts critical for the long-term health and survival of our planet. As the global population grows, the demand for resources escalates, leading to unprecedented environmental challenges (Mishra and Agarwal, 2025a).

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Traditional predictive models, while valuable, often fall short in accounting for the complex, nonlinear interactions inherent in natural phenomena (Mishra et al., 2025b). The accelerating biodiversity crisis demands innovative and scalable approaches for effective ecological monitoring and conservation. Digital Guardians of Nature: Emerging AI Technologies in Plant and Animal Surveillance explores the transformative role of artificial intelligence (AI) in revolutionizing plant and animal monitoring across diverse ecosystems (Mishra et al., 2025c). The convergence of Artificial Intelligence and Machine Learning with plant sciences is catalyzing a transformative shift in biodiversity conservation and ecological research. Traditional plant identification techniques, while foundational, are constrained by scalability, subjectivity, and reliance on expert taxonomists. In contrast, AI-powered methods—particularly those using deep learning architectures such as Convolutional Neural Networks, Support Vector Machines and Generative Adversarial Networks —demonstrate remarkable accuracy and efficiency in classifying plant species based on multimodal datasets including leaf morphology, flower phenotypes, and remote sensing imagery (Mishra et al., 2025d).

AI for Climate Modeling and Disaster Forecasting

Climate Modeling with Machine Learning and AI

Traditional climate models rely on computational fluid dynamics, energy balance models, and global circulation models (GCMs) to simulate Earth's climate system. While these methods are well-established, they are computationally intensive and require domain-specific expertise. AI, especially deep learning and reinforcement learning, offers new capabilities to improve both the efficiency and accuracy of climate predictions. AI models are increasingly being integrated with physical models to enhance their predictive skill, particularly in modeling nonlinear and chaotic climate systems (Reichstein et al., 2019). Artificial Intelligence (AI) is significantly enhancing the capacity of climate science to model and forecast complex Earth system dynamics. Traditional General Circulation Models (GCMs) simulate global climate processes using physics-based equations, but they are computationally expensive and often struggle with local or sub-seasonal resolution. Machine learning (ML) and deep learning (DL) approaches, particularly Long Short-Term Memory (LSTM) networks, convolutional neural networks (CNNs), and Transformer models, can learn from high dimensional datasets and capture spatiotemporal patterns in climate variables with greater efficiency (Ham et al., 2019; Reichstein et al., 2019). These AI methods have been applied to improve forecasts of phenomena such as El Niño-Southern Oscillation (ENSO), monsoonal shifts, and heat wave occurrences. Advanced generative models like Generative Adversarial Networks (GANs) are used to downscale low-resolution GCM outputs, generating high-resolution projections for regional planning and adaptation. AI also supports hybrid modeling strategies by coupling physical simulations with statistical learning algorithms to refine model outputs. This integration allows real-time updates based on observational data, enhancing model accuracy and adaptability (Stengel et al., 2020).

Disaster Forecasting and Early Warning Systems

The increasing frequency and intensity of climate-induced disasters require real-time and high precision forecasting systems. AI-powered early warning systems integrate meteorological, hydrological, and remote sensing data to predict and monitor extreme events such as hurricanes, floods, wildfires, and heat waves (Nguyen et al., 2021). Convolutional Neural Networks (CNNs) are used to analyze multispectral satellite imagery for early detection of wildfire hotspots. By learning spatial patterns in vegetation dryness, wind patterns, and temperature gradients, these models offer timely alerts to authorities and communities (Abade et al., 2021). For hydrological disasters, Support Vector Machines (SVMs) and Random Forest algorithms classify flood-prone areas using topography, soil type, and historical precipitation records. Machine learning algorithms also enhance disaster management through real-time event detection from diverse data sources such as weather stations, social media feeds, and drone surveillance. These tools facilitate rapid response and allocation of emergency resources, improving resilience and reducing human and economic losses (Rolnick et al., 2022). Disaster forecasting and early warning systems (EWS) are critical components of climate adaptation and risk reduction strategies, enabling timely detection, prediction, and communication of impending natural hazards such as floods, droughts, cyclones, landslides, wildfires, and tsunamis. The integration of Earth Observation (EO) data, numerical weather models, hydrological simulations, and AI-based forecasting algorithms has significantly enhanced the accuracy, lead time, and spatial resolution of modern EWS. High-resolution satellite data from missions like Sentinel-1 and -2, MODIS, and Landsat are used to monitor environmental precursors—such as rainfall anomalies, vegetation dryness, snowpack, sea surface temperature, and land deformation—feeding into predictive models that assess the likelihood and impact of disasters (Bhardwaj et al., 2021). AI and machine learning models, including recurrent neural networks (RNNs), long short-term memory (LSTM) networks, and hybrid ensembles, have been successfully applied to forecast extreme weather events by analyzing complex temporal patterns in meteorological, hydrological, and geospatial datasets. For instance, AI-enhanced flood forecasting systems developed by Google and national meteorological agencies can now predict river overflows and flash floods with lead times of 24–48 hours and high spatial granularity, providing critical alerts to at-risk communities (Jain et al., 2020). Similarly, wildfire EWS leverage real-time data from thermal imaging, vegetation indices, wind speed, and humidity sensors to generate dynamic fire risk maps, enabling preemptive evacuation and resource deployment. Digital platforms such as FEWS NET, GDACS, and UN-SPIDER integrate satellite observations, ground-based sensors, and socio-economic vulnerability data to deliver multi-hazard early warning information globally. In addition, Internet of Things

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(IoT) devices—including rainfall gauges, seismic sensors, and environmental monitoring stations—transmit live data to centralized platforms, facilitating community-based early warnings and local preparedness actions. However, challenges remain in ensuring data interoperability, community outreach, last-mile connectivity, and cross-border information sharing, particularly in low- and middle-income countries. Strengthening institutional capacity, promoting open data standards, and co-designing EWS with local stakeholders are essential for building inclusive and resilient disaster risk management systems.

GeoAI and Earth Observation Systems

GeoAI, or Geospatial Artificial Intelligence, represents the convergence of AI methodologies— particularly machine learning and deep learning—with geospatial data to analyze and interpret spatial phenomena. When integrated with Earth Observation (EO) systems, which collect data from satellites, UAVs, and ground-based sensors, GeoAI provides transformative capabilities for environmental monitoring, resource management, and disaster response. EO systems generate massive volumes of multi-resolution, multi-temporal data, including optical, radar, and thermal imagery. GeoAI techniques, especially convolutional neural networks (CNNs), recurrent neural networks (RNNs), and graph neural networks (GNNs), enable the automated classification, segmentation, and change detection of these complex datasets with high accuracy and speed. For instance, in land cover classification, GeoAI has significantly improved the spatial resolution and thematic accuracy of maps derived from Sentinel-2 and Landsat imagery, achieving classification accuracies exceeding 90% in heterogeneous landscapes (Zhu et al., 2017; Ma et al., 2019). In the domain of disaster management, GeoAI-driven analysis of pre- and post-event satellite images can quickly assess flood extent, wildfire damage, or infrastructure collapse, often within hours of image acquisition. Tools like Google Earth Engine and Microsoft's Planetary Computer have democratized access to cloud-based EO data processing, while integrating AI models to facilitate large-scale environmental analytics (Gorelick et al., 2017). Moreover, the synergistic application of EO and GeoAI is pivotal for climate action—tracking glacier retreat, deforestation, urban sprawl, and agricultural dynamics. For example, recent efforts have used deep learning on SAR (Synthetic Aperture Radar) data to monitor deforestation in cloudy tropical regions where optical data is unreliable (Ban et al., 2020). Despite these advances, challenges remain in terms of model generalizability, explainability, and the need for labeled training data across diverse geographies. Nonetheless, the fusion of EO and GeoAI is ushering in a new paradigm of "intelligent Earth observation" capable of near-real-time planetary monitoring, crucial for achieving Sustainable Development Goals (SDGs) and effective climate adaptation strategies.

Challenges and Ethical Considerations

While digital science offers transformative potential, several challenges remain. Data accessibility is uneven, particularly in the Global South, where lack of infrastructure and satellite coverage hinders comprehensive environmental monitoring (Arvor et al., 2020). AI models trained on limited or biased datasets risk misrepresenting ecological realities, leading to flawed decisions. Ethical issues also arise from surveillance technologies, especially concerning indigenous lands and wildlife habitats. Additionally, the carbon footprint of large-scale AI models and cloud computing must be addressed to ensure net-positive climate contributions (Strubell et al., 2019). Despite the transformative potential of GeoAI and Earth Observation (EO) technologies for environmental monitoring and decision-making, a range of technical, ethical, and socio-political challenges must be addressed to ensure their responsible development and equitable deployment. Data Quality, Heterogeneity, and Accessibility One of the primary technical challenges lies in managing the massive volume, variety, and velocity of EO data. These datasets often come from diverse sources—optical sensors, radar, LiDAR, in situ measurements—with differing spatial, temporal, and spectral resolutions. This heterogeneity complicates data fusion and analysis, leading to inconsistencies in outputs and reduced model reliability. Additionally, while some EO data (e.g., Sentinel, Landsat) is freely available, high-resolution commercial satellite imagery remains expensive and restricted, limiting access for researchers and decision-makers in low-resource settings. Bridging the digital divide in EO access is critical to ensuring global environmental equity.

Algorithmic Bias and Model Generalizability

AI models used in GeoAI applications often suffer from training data biases, which can lead to inaccuracies in underrepresented regions or ecosystems. For instance, land cover classification models trained primarily on European or North American datasets may perform poorly in the tropics or arid regions due to ecological variability. Such algorithmic bias can skew analyses and policy interventions, inadvertently reinforcing environmental injustices. Furthermore, many deep learning models are "black boxes," lacking interpretability and transparency, which hampers their acceptance in high-stakes environmental decision-making processes. Improving model explainability and generalization across geographies is essential for building trust and scientific validity.

Ethical Use of Surveillance Technologies

The increasing use of high-resolution EO systems and drones raises ethical concerns around privacy, surveillance, and consent—especially when monitoring human settlements, indigenous territories, or conflict zones. While these technologies can support environmental justice and disaster response, they can also be co-opted for surveillance or military purposes. Ethical frameworks must govern the collection, sharing, and use of geospatial data,

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ensuring that they do not violate human rights or disproportionately impact vulnerable communities. The Geospatial Data Ethics Charter and AI for Earth Principles advocate for transparency, inclusivity, and harm mitigation in data use (Young et al., 2019).

Environmental and Computational Sustainability

GeoAI workflows often require high-performance computing (HPC) infrastructure and cloud services to process petabytes of EO data, raising concerns about the carbon footprint of model training and data storage. For example, training a large deep learning model can emit as much carbon as five cars over their lifetime (Strubell et al., 2019). Sustainable AI development demands greener computing practices, energy-efficient algorithms, and the integration of life cycle assessments in digital twin and EO projects. The paradox of using resource-intensive technologies to monitor environmental sustainability must be critically addressed.

Governance, Accountability, and Equity

The governance of EO and GeoAI systems remains fragmented across national, institutional, and private domains. There is a pressing need for clear regulatory standards for data ownership, intellectual property, algorithmic accountability, and cross-border data sharing. Public-private partnerships must balance innovation with the public interest, ensuring that EO benefits are equitably distributed and not monopolized by tech giants or geopolitical powers. Incorporating indigenous knowledge systems, local participation, and environmental justice principles into EO governance can foster inclusive and context-sensitive solutions. To overcome these challenges, inclusive governance frameworks, equitable data sharing protocols, and sustainable computing practices are essential. Integrating ethical AI principles and local stakeholder engagement will be key to achieving responsible and effective digital transformation.

Conclusion and Future Directions:

Digital science, powered by AI, IoT, and geospatial analytics, offers transformative tools for addressing the climate and biodiversity crises. As Earth system processes become increasingly dynamic and interconnected, the ability to analyze massive datasets in near-real time will be indispensable for planetary stewardship. Future directions include the development of explainable AI (XAI) to enhance transparency and trust in climate modeling. Expanding open access data platforms, such as Copernicus and Earth Data, will democratize environmental intelligence. Integrating indigenous knowledge with digital technologies can enhance contextual accuracy and cultural relevance of ecological models. Moreover, advances in quantum computing promise to solve complex optimization problems in climate modeling and resource allocation. The fusion of digital innovation with ecological intelligence represents a powerful frontier for safeguarding life on Earth in the Anthropogenic epoch.

References:

1. Abade, N., et al., (2021). Predicting wildfire risk using machine learning. Ecological Modelling, 440, 109341.
2. Aldridge, R. C., Roantree, P., & O'Neill, R. (2020). Use of unmanned aerial vehicles (UAVs) in monitoring ecological restoration: Current applications and future directions. Ecological Engineering, 153, 105877.
3. Alonzo, M., Andersen, H. E., & Morton, D. C. (2021). Lidar remote sensing for forest carbon monitoring: Current status and future directions. Current Forestry Reports, 7, 1–13.
4. Amato, F., Guarino, F., Moscato, V., Picariello, A., & Sperli, G. (2020). Deep learning for intelligent Earth observation: A survey. IEEE Geoscience and Remote Sensing Magazine, 8(3), 49–71.
5. Arvor, D., et al., (2020). Addressing the unequal access to Earth observation data. International Journal of Digital Earth, 13(1), 1–19.
6. Ban, Y., Jacob, A., & Gamba, P. (2020). Space borne SAR data for global urban mapping at 30 m resolution using a robust urban extractor. ISPRS Journal of Photogrammetry and Remote Sensing, 166, 49–63.
7. Bhardwaj, A., Joshi, P. K., & Singh, S. (2021). Satellite-based early warning systems for disaster risk reduction: Opportunities and challenges. Natural Hazards, 109, 151–176.

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Original Article

Network and Social Computing: Catalyzing Digital Awareness, Financial Inclusion and Socio-Economic Transformation in India

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Abstract

The Network and Social Computing integrate computer networks with social interaction and human behaviour, enabling large-scale communication, collaboration, and information diffusion. In India, the widespread adoption of social networking platforms, affordable smartphones, and government digital initiatives have accelerated digital literacy and economic participation. This paper examines the role of social computing in promoting digital awareness, enhancing financial inclusion, and transforming business practices in India. Using secondary data from academic research, government reports, and recent national developments, the study highlights how social networks influence trust, technology adoption, and socio-economic outcomes. Findings indicate that effective use of social platforms and digital infrastructure can significantly strengthen inclusive growth and empowerment.

Keywords: *Social Computing, Digital Awareness, Financial Inclusion, Social Networks, Digital India.*

Introduction

Social Networking Services (SNS) are web-based platforms that allow users to build and maintain social relationships based on shared interests, activities, or real-world connections. Platforms such as Facebook, Twitter, Instagram, and LinkedIn facilitate content creation, real-time interaction, and global communication. The interdisciplinary field of Network and Social Computing examines how digital platforms influence individual behaviour, organizational strategies, and societal development. India's digital transformation has accelerated due to increased smartphone penetration, affordable internet, and initiatives such as Digital India and the JAM (Jan Dhan–Aadhaar–Mobile) trinity, expanding access to financial services, information, and governance tools.

Network and Social Computing integrate concepts from computer science, sociology, data science, and communication studies to analyze how individuals and groups connect, communicate, and influence each other in online environments. These platforms generate massive volumes of data, enabling researchers to understand patterns of interaction, information diffusion, opinion formation, and community development at an unprecedented scale. This paper aims to explore the concept of Network and Social Computing, examine the role of social media in modern society, and analyze its benefits and challenges. By understanding how digital networks influence human behaviour, we can better utilize these technologies for positive social, economic, and academic outcomes.

Social Computing and Digital Infrastructure in India

India's digital ecosystem has evolved rapidly, with smartphones and low-cost internet expanding access to social platforms. Key initiatives include:

- **UPI (Unified Payments Interface):** Enabled seamless digital transactions, increasing household participation in formal financial systems.

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- **Digital Nari Program:** Provides rural women with digital tools and financial service training, supporting entrepreneurship and self-reliance.
- **Digital India:** Improves digital literacy and access to e-services across urban and rural areas.

These developments demonstrate the critical role of social computing in **digital awareness** and **financial inclusion**.

Social Networking Tools and Engagement Platforms

Tool	Function	Impact
Crowd Booster	Engagement analytics	Optimizes content reach
Social Flow	Timing & audience targeting	Improves message effectiveness
Bitly	Link analytics	Tracks engagement metrics
Every Post	Cross-platform posting	Enhances brand presence
Sprout Social	Monitoring & reporting	Supports data-driven strategy
Buffer	Scheduling tools	Ensures consistent content
HootSuite	Multi-network management	Centralizes operations
SocialOomph	Scheduling + automation	Streamlines SNS activity

These tools help organizations and individuals leverage social computing for marketing, community engagement, and information dissemination.

Digital Awareness and Financial Inclusion

Social networks significantly increase access to information and financial services. India's Financial Inclusion Index shows rising participation in digital payment systems and welfare programs. Peer influence and community engagement play a key role in promoting responsible financial behaviour, particularly among women and marginalized groups.

Challenges:

- **Misinformation:** Rapid SNS growth can spread misleading content.
- **Privacy & Security Risks:** Personal data may be vulnerable to cyberattacks.
- **Digital Divide:** Rural and gender gaps remain in access and usage.

Advantages and Challenges of Social Computing

Advantages:

- Enhanced global connectivity
- Access to real-time information
- Economic opportunities and networking
- Support for collaborative learning
- Community building and activism

Challenges:

- Misinformation and bias
- Privacy and cybersecurity risks
- Digital divide and unequal access
- Social media addiction and distraction

Limitations

- Reliance on secondary data limits real-time analysis.
- Rapid technological changes may reduce the long-term applicability of findings.
- Focus is primarily on India, limiting global generalizability.

References

1. Economic Survey 2025–26: UPI's role in financial inclusion and credit expansion.
2. NITI Aayog partnership with NIIT Foundation for digital literacy and coverage expansion.
3. 'Digital Nari' initiative empowering rural women through digital tools and financial services.
4. India's Financial Inclusion Index, 2025.
5. Gopalakrishnan et al., "Community norms, peer influence, and women's digital financial inclusion," 2024. Kurde& Singh, "Next Generation Technologies for Secure Future Communication based Social Media 3.0," 2024.
6. Internet & Mobile Association of India, "Digital Adoption Report 2025."

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Cyber Security in Fintech, Payment and Amp; E-Commerce

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Abstract

Cyber security is a critical concern for fintech, payment, and e-commerce industries. This article explores the importance of cyber security, its role, advantages, and best practices for protecting sensitive financial information in these sectors.

As of 2026, the convergence of Financial Technology (Fintech) and E-commerce has created a "frictionless" economy. However, this convenience has expanded the attack surface for AI-driven threats and sophisticated fraud. This paper explores how cybersecurity has transitioned from a backend IT function to a foundational pillar of Trust Architecture. We analyze the shift from perimeter defense to Zero-Trust 2.0, the impact of the Digital Operational Resilience Act (DORA), and the emergence of Quantum-Resistant Cryptography in protecting global payment flows.

Introduction

The rapid growth of fintech, payment, and e-commerce has increased cyber threats. Protecting sensitive data is crucial for maintaining customer trust and financial stability. As digital transactions become the norm, ensuring robust cyber security measures is paramount.

In today's digital age, protecting sensitive information and systems from cyber threats is crucial. Cyber security refers to the practices, technologies, and processes designed to safeguard digital assets, networks, and data from unauthorized access, use, disclosure, disruption, modification, or destruction.

As we increasingly rely on digital platforms for financial transactions, e-commerce, and communication, the risk of cyber-attacks grows. Cyber security is essential for individuals, businesses, and governments to ensure confidentiality, integrity, and availability of digital information.

Meanings:

Cyber Crime: Cybercrime refers to criminal activities conducted through digital networks or computers. It includes offenses like hacking, phishing, identity theft, and more, targeting individuals, businesses, or governments. Think of it like real-world crime, but in the digital space.
Cyber Security: Protection of digital systems, networks, and data from cyber-attacks.
Example: Using encryption to protect online banking transactions.
Fintech: Financial technology combining finance and technology to deliver services.
Example: Mobile payment apps like Paytm or Google Pay.
E-commerce: Electronic commerce involving online transactions.
Example: Shopping on Amazon or Flipkart.
AMP: AMP likely refers to *Accelerated Mobile Pages*, a web technology for faster mobile browsing. In the context of fintech, payment, and e-commerce, AMP can enhance user experience by making websites load faster on mobile devices.

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Cyber Crimes in India:

Cybercrime in India is a rapidly growing concern. With increasing digital adoption, the country faces threats like financial fraud, identity theft, hacking, and online frauds.

- ₹31,500 crore lost due to cybercrime between 2019-2024
- 53.93 lakh cybercrime complaints registered on the National Cybercrime Reporting Portal (NCRP) from 2019 to 2024
- 24.38% increase in cybercrime cases in 2022 compared to 2021
- 11 cyberfraud cases booked in Kodagu district within 3 weeks, with total losses of ₹2.4 crore
- ₹3,000 crore lost to "digital arrest" scams in January 2026 alone

Some common types of cybercrimes in India include:

- **Financial Fraud:** Phishing, UPI scams, and online investment scams
- **Identity Theft:** Stolen Aadhaar, PAN, or bank details used for impersonation
- **Cyberstalking and Harassment:** Online bullying, threats, or defamation
- **Ransomware Attacks:** Hackers demand payment to restore access to encrypted data

Types of Cybercrimes

- **Phishing**: Social engineering attacks stealing sensitive info (e.g., fake emails asking for bank details).
- **Malware:** Malicious software disrupting systems (e.g., ransomware locking user data).
- **SQL Injection**: Attacks targeting databases (e.g., extracting credit card info from an e-commerce site).
- **DDoS Attacks:** Overwhelming systems to disrupt service (e.g., bringing down a payment gateway).

Case Studies

1. Phishing Attack (Indian Bank, 2020)

What happened: Attackers sent fake SMS alerts to customers, tricking them into sharing sensitive info.
Impact: ₹1.15 crore stolen from customers' accounts.
Source: RBI Annual Report 2020, The Economic Times.
Takeaway: Phishing exploits human trust; awareness and verification are key.

2. **Ransomware Attack (E-commerce Platform, 2019)**

What happened: Attackers locked the platform's data, demanding ransom.
Impact: Operations disrupted, leading to financial losses
Source: ET Telecom.
Takeaway: Ransomware can cripple businesses; backups and security measures are crucial.

3. SQL Injection (Fintech App, 2021)

What happened: Attackers exploited database vulnerabilities, accessing user data.
Impact: User data compromised.
Source: TechCrunch, The Hindu BusinessLine.
Takeaway: Input validation and security audits prevent such breaches.

4. DDoS Attack (Payment Gateway, 2020)

What happened: Attackers overwhelmed the gateway with traffic, disrupting service.
Impact: Temporary service disruption.
Source: The Times of India, Akamai Security Report.
Takeaway: DDoS protection and redundancy help maintain service availability.

Cyber security industry

The cyber security industry provides solutions to protect digital assets, including threat detection, incident response, and security consulting. Example: Companies like Palo Alto Networks and Crowd Strike offer advanced threat protection services.

The finch cyber security market is experiencing rapid expansion, projected to reach $312.76 billion by 2030 with a 9.4% CAGR, driven by the need to secure digital payments and data. As digital adoption grows—with the Indian fintech market alone expected to add $400 billion by 2029—robust security, AI-driven fraud detection, and regulatory compliance are essential for maintaining user trust.

Cyber security in India & global

INDIA:

1. **Regulatory Framework:** RBI, CERT-In, and MEITY regulate cyber security.
2. **Initiatives:** National Cyber Security Policy, Cyber Swachhta Krum, and Digital India.
3. **Challenges:** Growing cyber threats, skill gap, and awareness.

Global:

1. **Regulations:** GDPR (EU), CCPA (California), and NIST (US).
2. **Threats:** Ransomware, phishing, and nation-state attacks.

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3. **Collaborations:** International cooperation, bug bounty programs, and info-sharing.

Cyber Security Acts in India

1. Information Technology Act, 2000 (IT Act): Primary law addressing cybercrimes and data protection.
- Sections 65-74: Tampering with computer source documents, hacking, etc.
- Section 72: Breach of confidentiality and privacy.
2. Information Technology (Amendment) Act, 2008: Updated IT Act for emerging technologies.
3. RBI Cyber Security Guidelines: Mandates security measures for financial institutions.
4. Personal Data Protection Bill, 2019: Proposed legislation for data protection (awaiting approval)

Role & Importance of Cyber Security

Cyber security protects:

1. **Sensitive financial data:** Safeguards personal and financial information (e.g., credit card details, passwords).
2. **Prevents financial losses:** Reduces risks of theft and fraud (e.g., phishing, ransomware).
3. **Maintains customer trust:** Ensures secure transactions and protects reputation.
4. **Ensures regulatory compliance:** Adherence to guidelines like RBI, PCI-DSS, GDPR.

Advantages of Cyber Security

1. **Data Protection:** Safeguards personal and financial info.
2. **Reduced Risk:** Minimizes cyber-attack risks and losses.
3. **Trust and Reputation:** Builds customer trust.
4. **Compliance:** Ensures adherence to regulations.

Challenges of Cyber Security

1. **High Implementation Costs:** Robust security can be expensive.
2. **Complexity:** Managing security systems is resource-intensive.
3. **False Sense of Security:** Over Reliance on measures can lead to complacency.
4. **Impact on User Experience**: Stringent security can hinder convenience.

Methods of Cyber Security

Firewalls:

A firewall is like a bouncer at a club. It monitors and controls incoming and outgoing network traffic based on predefined rules, blocking suspicious activity. Think of it as a barrier between your system and potential threats.

Types of Firewalls;

i. **Hardware Firewalls:** Built into routers or devices.
ii. **Software Firewalls:** Installed on individual devices.
iii. **Cloud Firewalls:** Protect cloud-based infrastructure.

Key Functions

- Packet Filtering: Examines data packets and blocks based on rules.
- Stateful Inspection: Tracks connection states for better filtering.
- Proxy Services: Acts as an intermediary for added security.

Encryption:

Encryption is like sending a secret message in a locked box. It converts data into a coded format, making it unreadable to unauthorized parties. Only those with the decryption key can unlock and access the info.

Key Types:

i. **Symmetric Encryption:** Same key for encryption and decryption (e.g., AES).
ii. **Asymmetric Encryption:** Pair of keys – public for encryption, private for decryption (e.g., RSA).

Common Uses

- **Data Protection:** Secure sensitive info like passwords, transactions.
- **Secure Communications:** Protect emails, messages, and online transactions.
- **Compliance:** Meet regulatory requirements (e.g., GDPR, RBI guidelines).

Multi-factor Authentication (MFA):

MFA is like adding extra locks to your door. It requires two or more verification methods to confirm identity, making unauthorized access tougher. Common factors include:

i. **Something you know:** Passwords or PINs.
ii. **Something you have:** OTPs, smart cards, or authenticator apps.
iii. **Something you are:** Biometrics like fingerprints or facial recognition.

Why MFA?

- Enhanced Security: Reduces risk of breaches even if passwords are compromised.

- Regulatory Compliance: Often required for standards like PCI-DSS, GDPR.

Examples

- Google Authenticator app for OTPs.
- UPI PIN + biometric for payments.

Intrusion Detection Systems (IDS):
IDS is like a security guard monitoring CCTV feed. It detects suspicious activity on networks or systems, alerting admins to potential threats.
Types
i. **Network IDS (NIDS):** Monitors network traffic.
ii. **Host IDS (HIDS):** Focuses on individual devices.

Key Functions

- **Signature-based Detection:** Identifies known threats.
- **Anomaly-based Detection:** Spots unusual patterns.
- **Alerts and Responses**: Notifies admins for action.

Regular Updates and Patches:
Regular updates and patches are like routine vehicle maintenance. They fix vulnerabilities, improve performance, and protect against exploits.
Why?
i. **Security Fixes:** Patch vulnerabilities hackers might exploit.
ii. **Bug Fixes:** Improve stability and functionality.
iii. **Compliance:** Meet regulatory requirements.

Best Practices

- Automate Updates: Enable auto-updates where possible.
- Test Patches: Validate in a controlled environment first.
- Prioritize Critical Systems: Focus on high-risk areas.

Employee Training:
Employee training is like teaching everyone to be their own security guard. Educating staff on cyber threats and best practices can prevent breaches.

Key Topics
i. **Phishing Awareness:** Spot suspicious emails/links.
ii. **Password Hygiene:** Use strong, unique passwords.
iii. **Safe Browsing:** Avoid risky websites.
iv. **Data Protection:** Handle sensitive info carefully.

Best Practices

- **Regular Sessions:** Conduct periodic training.
- **Simulated Attacks:** Test employees with mock phishing.
- **Clear Policies:** Define security expectations.

Incident Response Plan:
An Incident Response Plan is like a fire drill. It's a structured approach to managing security breaches or cyber attacks.
Key Components
i. **Preparation:** Define roles, tools, and processes.
ii. **Identification:** Detects and confirms incidents.
iii. **Containment:** Limit damage and prevent spread.
iv. **Eruption:** Eradicate the threat.
v. **Recovery:** Restore systems and data.
vi. **Lessons Learned:** Review and improve the plan.

Best Practices

- **Document Everything:** Keep detailed records.
- **Communicate Effectively:** Coordinate teams and stakeholders.
- **Test and Update:** Regularly review and refine the plan.

Advanced Methods
1. Artificial Intelligence (AI) and Machine Learning (ML):
AI and ML are like super-smart analysts. They're transforming cyber security by predicting threats, automating responses, and analyzing vast data.

Key Applications
i. **Threat Detection:** Identify patterns and anomalies.
ii. **Predictive Analytics:** Forecast potential attacks.
iii. **Automated Responses:** Quarantine threats in real-time.
iv. **Phishing Detection:** Analyze emails and block scams.

Benefits
- **Faster Response:** Reduce breach impact.
- **Proactive Defense:** Stay ahead of evolving threats.
- **Reduced Human Error:** Automate routine tasks.

Cloud Security:
Cloud security is like safeguarding your belongings in a shared apartment. Protecting data, apps, and infrastructure in cloud environments is crucial.

Key Aspects
i. **Data Encryption:** Protect data in transit and at rest.
ii. **Access Controls:** Manage who can access cloud resources.
iii. **Compliance:** Meet regulatory requirements (e.g., GDPR, HIPAA).
iv. **Monitoring:** Track cloud activity and detect threats.

Best Practices
- **Use Strong Passwords:** Enforce MFA for cloud accounts.
- **Segment Data:** Limit access to sensitive info.
- **Regular Audits:** Check cloud configurations and security.

Endpoint Security:
Endpoint security is like protecting every door in a house. Securing devices (laptops, mobiles, etc.) from threats is crucial.

Key Aspects
i **Antivirus/Anti-malware:** Detects and blocks threats.
ii. **Device Control:** Manage access to USBs, etc.
iii. **Patch Management:** Keep software updated.
iv. **Encryption:** Protect data on devices.

Best Practices
- **Install Security Software:** Use reliable endpoint protection.
- **Regular Updates:** Keep OS and apps updated.
- **Employee Training:** Teach safe device usage.

Conclusion
As fintech, payment, and e-commerce sectors continue to evolve, robust cyber security measures are crucial for protecting sensitive data and ensuring trust. Implementing encryption, MFA, regular updates, and comprehensive employee training can significantly reduce risks. AI-driven threat detection, cloud security, and incident response plans further bolster defenses.

By prioritizing cyber security, businesses can build trust, ensure compliance with regulatory requirements, and provide a safer digital experience for customers. A robust security posture not only protects assets but also fosters growth and innovation in the digital economy.

Recommendations
- Protect Sensitive Data: Encryption and access controls are foundational, safeguarding financial information and personal data.
- Stay Vigilant: Regular updates, patches, and continuous monitoring help identify vulnerabilities and prevent breaches.
- Educate Users: Employee and customer awareness drives a security culture, reducing phishing and social engineering risks.
- Proactive Defense: Leverage AI, ML, and threat intelligence to stay ahead of emerging threats.

References
1. Phishing case study (Indian bank, 2020):
RBI Annual Report 2020: https://rbi.org.in/Scripts/AnnualReportPublications.aspx
The Economic Times: https://economictimes.indiatimes.com/news
2. Ransomware attack on e-commerce platform (2019):

ET Telecom: https://telecom.economictimes.indiatimes.com/
3. SQL Injection case study (Indian fintech app, 2021): TechCrunch: https://techcrunch.com/
The Hindu Business Line: https://www.thehindubusinessline.com/
4. DDoS attack on payment gateway (2020):The Times of India: https://timesofindia.indiatimes.com/ Akamai Security Report: https://www.akamai.com/security-threat-report
5. RBI penalty for non-compliance (2021): RBI Press Release: https://www.rbi.org.in/Scripts/PressReleases.aspx
Money control: https://www.moneycontrol.com/

General sources:

1. RBI Cyber Security Guidelines: https://www.rbi.org.in/scripts/NotificationUser.aspx?Id=11870
2. PCI-DSS Standards: https://www.pcisecuritystandards.org/document

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Original Article

Role of cybersecurity Frameworks in risk management

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Abstract

In the contemporary digital era, organizations rely extensively on interconnected information systems, cloud platforms, and online communication technologies to perform operational and strategic activities efficiently. While digital transformation has enhanced productivity and accessibility, it has also increased exposure to cyber threats such as ransom ware, phishing, malware, insider misuse, and data breaches. These cyber incidents can result in financial loss, operational disruption, reputational damage, and legal consequences. Effective risk management has therefore become essential for protecting information assets and ensuring business continuity. Cyber security frameworks provide structured guidelines and standardized approaches that help organizations identify, assess, and mitigate cyber risks. This paper examines the role of major frameworks including the NIST Cyber Security Framework, ISO/IEC 27001, and CIS Critical Security Controls in strengthening risk management. It also explains how these frameworks support risk identification, assessment, implementation of security controls, continuous monitoring, and incident response. The study concludes that adopting suitable cyber security frameworks improves organizational resilience and supports secure and sustainable digital operations.

Keywords: *Cyber Security, Risk Management, NIST, ISO 27001, Information Security, Cyber Threats*

Introduction

The rapid advancement of digital technologies has transformed the functioning of modern organizations. Organizations across sectors such as banking, healthcare, education, e-commerce, and government increasingly depend on digital platforms, cloud computing, and network infrastructure to perform daily operations efficiently. While digital transformation has improved connectivity and productivity, it has also increased exposure to cyber threats. Cyber-attacks such as ransom ware, phishing, malware infections, and denial-of- service attacks are becoming more frequent and sophisticated, posing significant risks to sensitive data and organizational systems. These cyber incidents may cause financial losses, compromise confidential information, disrupt operations, and damage reputation.

In this environment, effective risk management is essential for identifying, evaluating, and minimizing cyber risks Cyber security frameworks provide structured and systematic approaches that help organizations manage risks, implement appropriate security controls, and maintain business continuity in a digitally connected world

Objectives

The primary objective of this research is to analyze the role of cyber security frameworks in risk management. The study aims to understand how frameworks such as NIST, ISO/IEC 27001, and CIS Critical Security Controls help organizations identify and mitigate cyber risks. Another objective is to evaluate the benefits and challenges associated with implementing cyber security frameworks. The research also aims to examine how these frameworks support regulatory compliance, improve governance, and strengthen organizational resilience against evolving cyber threats.

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Literature Survey (Base Paper)

Previous research emphasizes the importance of adopting structured cyber security frameworks for effective risk management. Studies on the NIST Cyber Security Framework highlight its ability to improve risk-based decision-making and incident response. Research on ISO/IEC 27001 demonstrates its role in strengthening information security management and regulatory compliance. Literature on CIS Critical Security Controls indicates that prioritized security practices significantly reduce system vulnerabilities and cyber incidents. Collectively, these studies show that implementing standardized frameworks enhances organizational security posture and improves cyber risk management capabilities.

Cyber Security

Frameworks Cyber security frameworks consist of structured standards, guidelines, and best practices designed to protect information systems and manage cyber risks effectively. The NIST Cyber Security Framework is based on five core functions: Identify, Protect, Detect, Respond, and Recover, enabling organizations to manage cyber risks systematically. ISO/IEC 27001 provides an international standard for establishing an Information Security Management System and emphasizes continuous risk assessment and improvement. CIS Critical Security Controls provide prioritized practical measures such as asset management, access control, vulnerability management, and data protection. These frameworks help organizations establish strong governance, improve security awareness, and adopt a risk-based approach to cyber security management.

Risk Management in Cyber Security

Risk management in cyber security involves identifying threats, assessing vulnerabilities, and implementing appropriate controls to minimize potential damage. Risk identification includes recognizing threats such as malware, phishing, insider misuse, and unauthorized access. Risk assessment evaluates the likelihood and potential impact of these threats on organizational operations. Risk mitigation involves implementing security measures such as firewalls, encryption, multi-factor authentication, intrusion detection systems, and regular updates. Continuous monitoring ensures that security controls remain effective against evolving threats. A structured risk management approach helps organizations prevent cyber incidents and make informed decisions regarding cyber security investments. 6. Role of Cyber Security Frameworks in Risk Management Cyber security frameworks play a vital role in strengthening organizational risk management. They provide structured methodologies for identifying cyber threats, evaluating risk levels, and implementing security controls. Frameworks promote continuous monitoring, vulnerability assessment, and real-time threat detection, enabling early identification of risks. They also support incident response and recovery, allowing organizations to minimize damage and restore operations efficiently. Furthermore, frameworks help organizations comply with regulatory requirements, improve governance, and enhance accountability, thereby strengthening overall cyber resilience.

Benefits and Challenges

The adoption of cyber security frameworks improves security posture, protects sensitive information, ensures regulatory compliance, and enhances decision making. Frameworks also support business continuity and improve incident response capabilities. However, implementing cyber security frameworks involves challenges such as high cost, requirement of skilled professionals, continuous monitoring, and integration complexity. Overcoming these challenges requires proper planning, adequate training, and strong management support.

Future Works

Future research may focus on integrating artificial intelligence and machine learning into cyber security frameworks for predictive risk management. Further studies can explore automated incident response, advanced threat intelligence, and zero-trust architecture. Future work may also examine improving framework adaptability for small and medium organizations and enhancing cyber security awareness and training.

Conclusion:

Cyber security frameworks provide a structured approach to managing cyber risks and improving organizational security posture. They support risk identification, mitigation, monitoring, and compliance. Despite challenges, adopting appropriate cyber security frameworks is essential for protecting digital assets, ensuring business continuity, and maintaining long-term stability in an evolving cyber threat landscape.

References

National Institute of Standards and Technology, NIST Cyber security Framework; ISO/IEC 27001 Information Security Management Standard; Center for Internet Security, CIS Critical Security Controls; Whitman and Mattord, Principles of Information Security; Stallings, Network Security Essentials

1. NIST Cybersecurity Framework; ISO/IEC 27001; CIS Critical Security Controls; Whitman and Mattord; Stallings; Anderson Security Engineering; Bishop Computer Security; ISACA COBIT; ENISA Risk Management; ISO 27005 Risk Management; NIST SP 800-53; NIST SP 800-37; OWASP Security Guidelines.
2. ISO/IEC 27002 – Code of Practice for Information Security Controls

3. ISO/IEC 27005 – Information Security Risk Management
4. NIST Special Publication 800-53 – Security and Privacy Controls
5. NIST Special Publication 800-37 – Risk Management Framework
6. ENISA – Cybersecurity and Risk Management Guidelines
7. ISACA – COBIT Framework for Governance and Management of Enterprise IT
8. OWASP Foundation – OWASP Top Ten Security Risks
9. Cloud Security Alliance – Cloud Controls Matrix
10. Verizon – Data Breach Investigations Report
11. Microsoft – Security Intelligence Report
12. Symantec – Internet Security Threat Report
13. Kaspersky – Global Cybersecurity Threat Reports
14. SANS Institute – Information Security Policy and Risk Management Resources
15. Anderson, Ross – Security Engineering
16. Bishop, Matt – Computer Security: Art and Science
17. Peltier, Thomas – Information Security Risk Analysis
18. Von Solms & Van Niekerk – From Information Security to Cyber Security
19. Gordon & Loeb – Managing Cybersecurity Resources

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Original Article

The Mirage of Knowledge: Analyzing the Roots and Impacts of LLM Hallucination in Education

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Abstract

The rapid advancement of Artificial Intelligence (AI), particularly in Large Language Models (LLMs), is restructuring the way humans acquire knowledge. As LLMs are being widely adopted across a variety of sectors, their integration in the educational sector presents critical challenges. One such critical challenge is hallucination. Hallucination refers to a model generating plausible yet factually incorrect and misleading responses. In educational settings, where students heavily rely on LLM technology for assignments, research, and exam preparation, such hallucinations can undermine the foundational knowledge of the learner. Hallucination is not a mere error in the codebase, but it is an inherent feature caused by training data and probabilistic architecture. This paper argues that to mitigate this severe risk, the educational sector must move beyond the use of a single LLM. It proposes the development of multi-LLM architecture, which will combine the strengths of different LLMs and give the best result to the learner, thereby mitigating the risk of hallucination. A human-in-loop strategy can be implemented to review the answers given by all LLMs, which will enable more strict segregation of responses, thereby giving the learner the best educational content without any hallucination.

Keywords: *Multi-LLM, Human-in-the-loop, System Prompt*

Introduction

The integration of LLM in education is increasing exponentially. The LLMs foster learners with all the academic material they need instantly without tediously surfing on the internet or referring to books. This makes LLMs their unofficial academic helpers. Students rely on LLM technology to clarify their doubts, to analyze their assessments, and to prepare for examinations. It can be helpful to students, especially in STEM field, which demands intense mathematics, complex concepts, and intricate coding. LLMs excel in all these domains and provide detailed responses, which can consist of codes, mathematics, and experiments. Such an approach encourages the learner to grasp the academic topic in every learning style [1], [2], [6].

However, the usage of a single LLM model possesses several critical disadvantages in the academic settings. One of the most severe concerns is hallucination. Hallucination is when an LLM system generates a confident, plausible-sounding, but factually incorrect or fabricated response [3]. It confuses the learner, which hampers his/her learning experience and creates a major hurdle in grasping knowledge. As a result, learners jeopardize their foundational knowledge and academic integrity. The hallucinated result may not align with the academic curriculum, resulting in confusion. Therefore, a single LLM system in educational settings carries high risks of hallucinations and is not a reliable or trustworthy solution for education. To solve this critical issue, a multi-LLM framework should be utilized in education, which consists of multiple LLMs based on their strengths in various domains. This research presents a multi-LLM framework consisting of three LLMs (ChatGPT, Gemini, and Perplexity sonar).

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All these LLMs are experts in academic settings in various ways. ChatGPT provides concise but accurate responses, Gemini provides responses that are detailed, and Perplexity sonar generates a thorough output that consists of all learning styles. The student's query is passed as an input to all three LLMs with the optional Retriever-Augmented Generation (RAG) feature. The three LLMs are given the same system prompt, and according to the system prompt, optional RAG content and the student's query, three responses will be generated [3], [4], [7].

To segregate the best response from the three responses, a human-in-loop mechanism can be initiated, wherein the evaluator can be an educator who is specialized in that academic domain [5], [8]. This submodule eradicates all the hallucinations in the system and therefore enhances the reliability and effectiveness of systems used for the educational sector. The proposed architecture ensures a well-generated response curated to all types of learning, resulting in an overall performance boost for the learner.

Related Work

The integration of AI in education presents challenges related to reliable content and misalignment with the academic curriculum. The existing research is broadly classified into three themes: personalization, technical challenges of hallucination, and effective AI-human collaboration framework.

Personalized Learning

Utilizing AI for personalization is a major focus in current EdTech research. Complex architectures like the AdaptLearn AI framework enable bidirectional personalization by adjusting information to the learner and fine-tuning the model based on the outcomes [1]. Pedagogical frameworks are changing to incorporate AI with creative teaching approaches like the "Four-in-One" model attempting to link various educational stages and methodologies [6]. These efforts show commitment to moving beyond one-size-fits-all instruction in the educational sector.

Hallucination Mitigation

The integration of personalized educational content generation is not efficient due to the presence of LLM hallucination. One of the most advanced solutions for this problem is incorporating RAG in the system architecture. To reduce fabricated responses, the researchers are investing in different RAG implementations so that LLM can generate responses with the help of verified content [3]. Appropriate retrievals are possible by effective similarity searches of similar embeddings in vector databases, which is essential for the system's robustness [7]. To develop more accurate and fast systems for AI education, more complex RAG approaches are essential, utilizing various indexing techniques and effective distance metrics [4]. The RAG ensures trustworthiness in the AI systems, which is a crucial technical foundation for replicating the traditional education system.

Human-AI collaboration

Research indicates that recent educational AI systems are incorporating hybrid approaches that treat AI as a tool and humans as decision makers. Researchers highlight how AI fosters critical thinking in learners, wherein AI is treated as a resource and is not given any authority [5]. This aligns with the view of AI as a versatile tool and "unpredictable" wildcard in computer science education [8]. The most complex ideas consisted of multi-agent AI systems that promote education and research by having several agents carry out specialized tasks under human supervision [9]. The current developments suggest the use of agentic AI in education, in which AI systems are directed by human-aligned objectives and supervision but display more autonomy and goal-directed behaviour [10]. Together, these studies argue that the solution for creating the best educational AI system is not autonomy but designing systems that incorporate both the computational power of AI and irreplaceable human expertise.

Research Gap

In summary, related work is advancing in three directions: developing adaptive educational systems [1], [2], [6], enhancing the factual reliability [3], [4], [7], and integrating human-AI collaboration [5], [8], [9], [10]. However, research that incorporates all these modules into a single framework is lacking. Few studies propose blueprints of frameworks that employ RAG, utilize multi-model for reliability, and embed the human-in-the-loop method to fulfill educational purposes. This paper addresses the gap by detailing such an integrated framework to reduce hallucination [3], [4] to foster critical thinking [5] and to integrate humans as decision makers in complex AI workflows [9], [10] in a personalized learning environment [1], [2].

Methodology

To address challenges of hallucination by single-LLM systems, this research proposes a human-in-loop multi-LLM system. It is developed to reduce hallucination rates by involving three elements, which are three LLMs, a knowledge base using RAG, and a human-in-the-loop method for evaluation. The fundamental principle of this mechanism is to have critical verification of academic content by utilizing multiple LLMs and a subject expert educator who acts as an evaluator. Therefore, the architecture follows a simple pipeline consisting of 4 modules, resulting in transforming a student query into a reliable, trustworthy response.

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A. Comparative Responses with Expert Analysis

The core problem in a single-LLM system is that the accuracy of the responses is questionable, especially in educational settings, due to the possibility of hallucination. Therefore, by generating three different responses to the same user query, the system creates a comparative scenario. Inconsistencies in these responses act as a built-in error detection system, resulting in reduced hallucination. The final pipeline module is evaluation by an expert who uses their specific domain knowledge to evaluate all three responses. The procedure ensures that the authority of the output belongs to the domain expert, resulting in improved trust and reliability in the system.

B. System Components

The system involves three modules, each chosen to make the system more robust and reliable. First, the multi-LLM module uses three state-of-the-art models (OpenAI ChatGPT, Google Gemini, and Perplexity AI sonar). They are selected because they are developed by different companies and have been trained on different amounts and qualities of data. These LLMs have different types of biases, temperatures, and reasoning styles. This diversity makes it less likely that all three LLMs will commit the same error, thereby ensuring different types of explanations.

Second, to achieve factual accuracy in response, the RAG module is incorporated. After the initial student question, the question queries the RAG database consisting of lecture notes, reference books, and research articles. The appropriate content related to the question is attached with the question, and the elaborated system prompt will be sent to LLM [3], [4].

The third component is the human-in-the-loop module, included for clarity and efficiency. The experts are provided with dashboards consisting of the question, retrieved source materials, and three different responses. The expert has to evaluate the content based on their subject expertise. The evaluator acts as a judge, evaluating which parts of the responses are correct and clear [9], [10].

C. Operational Workflow

A learner submits a query via a platform as input. The system scans the vector database and retrieves relevant content. The query, retrieved content, and system prompt act as an elaborate description for the LLM to generate a detailed and accurate response. The three responses are then submitted to the expert for evaluation. The evaluator rates the answers based on accuracy, depth, and clarity or can discard the AI-generated answer and provide their own explanation. The best response is pushed ahead in the pipeline, and it is given as the output.

D. Framework Effectiveness Assessment

The effectiveness of the system would be measured against the current usage of single LLM systems. The most important metric for assessment is reduction in factual errors in the academic content. It will ensure that the learner gets the best response without having a doubt of hallucinated outputs. As a result, reduction of hallucination and increase in trustworthiness are expected to encourage learner adoption of the system, thereby improving overall learning outcomes [3], [4].

Results and Discussion

A. Experimental Setup

To analyze the efficiency of the framework, a sample query from a student studying in data science was used. The query was "Explain NumPy practically." The query is specific, requiring the RAG module to retrieve relevant content. The three LLMs utilized in this framework are OpenAI's GPT-4, Google Gemini 2.5, and Perplexity AI's sonar. The expert was a professor of data science.

Fig. 1 shows the exact system prompt delivered to all three models. It was designed to enforce transparency and factual accuracy. In the system prompt, there are several placeholders to fill in the information required for the LLM's response generation. The topic placeholder is the student's query, whereas the style instruction placeholder analyzes the learning style (detailed, practical, experimental, and conceptual). The context placeholder stores the retrieved chunks from the RAG database.

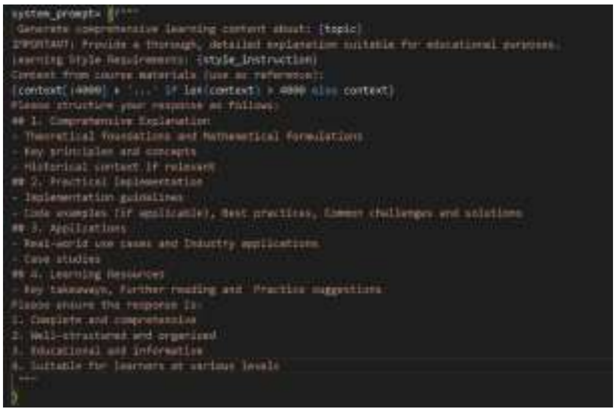

Fig. 1 Image showing the system prompt used in the framework

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B. Multi-LLM Response Generation and Comparative Analysis

The three LLMs generated distinct responses, based on identical input from Fig. 1. Fig. 2 displays these three shortened responses side-by-side for comparative analysis.

Fig. 2 Visual logs of text output from GPT-4, Gemini 2.5, and Perplexity AI sonar

All three models correctly identified the overall system prompt and the context. GPT-4 gave a factually accurate but concise response consisting of 4256 characters and therefore missed some key details. Gemini 2.5 generated the longest response of 12220 characters, which included the codebase, experiments, and recent advancements. However, the response was overwhelmingly detailed and ineffective in an educational context. Perplexity AI sonar generated an appropriate response, stating all the important details by utilizing 8003 characters, which is an ideal response for academic settings.

C. Response Evaluation

Due to diverse responses, the human-in-the-loop module plays a vital decisive role in deciding the best response. The expert immediately flagged GPT-4 as ineffective due to its concise response. The expert stated that GPT-4 did not cover all the details that are required for understanding of the learner, especially practical explanations, which are needed in practical topics such as "NumPy." The expert found Gemini's response to be theoretically detailed and verbose, which is not necessary in practical topics. The expert gave positive evaluations to Perplexity AI's sonar because sonar's response consisted of codes, experiments, recent advancements, and some references for minor projects along with theory. Therefore, Perplexity AI's sonar was the highest rated, followed by Google's Gemini 2.5 and then OpenAI's GPT-4.

D. Redefining the Educator's Role in the Era of AI

The results demonstrated that the role of professor was vital and irreplaceable but evolved. The system architecture did not automate the evaluation of responses using an evaluator agent, thereby using the professor's expertise and experience for evaluation. The professor acted as a curator and verifier, applying the mastery to assess the responses—a task that is poorly performed by LLMs [4]. The shift of educators' effort from creating academic content from scratch to assessing the quality of AI-generated academic content makes the teaching and knowledge sharing more scalable and reliable [5].

E. Limitations and Future Directions

The proof-of-concept is limited by its scope due to a single case study. A robust validation required a large-scale, multi-LLM pipeline framework to quantify the hallucination rate by comparing it to a baseline single LLM system [3]. The future work should also investigate the cost, thereby providing insights on the affordability of the framework. Ultimately, this framework is not a final product but a blueprint for a responsible hybrid approach in the educational sector, where AI generates detailed explanations, but human expertise continues to be the ultimate authority of truth—a primary principle for education [9], [10].

Conclusion

This research has argued that using a single LLM system in the educational sector possesses a risk of hallucination. Hallucinations are not software bugs but inherent features due to probabilistic design contained in LLM architecture. The proposed multi-LLM evaluation framework addresses the hallucination by implementing a human-in-

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the-loop module in the architecture, thereby evaluating all the responses, resulting in a reduction of hallucination rates. The transformation of the educator's role to evaluator and curator ensures the robustness of using a hybrid approach, wherein the human expertise decides the best output response. This approach is suitable for the educational sector because the educator's expertise remains the non-negotiable authority on accuracy and curriculum alignment. However, the current architecture presents practical challenges such as computational cost and the requirement for a readily available educator. Future research should focus on optimizing the architecture, exploring cost-effective or open-source LLMs specializing in educational contexts, and conducting large-scale studies to quantify gains in accuracy and efficiency.

In conclusion, it is important to integrate LLM technology with subject-matter expertise, especially in education. The future scope of integrating AI in education is immense, but the approach of integration should not affect the traditional effective learning approaches present among learners. The research states that human judgment is irreplaceable and should be centered while integrating LLMs in workflows. We can utilize the immense potential of LLM technology without hampering the foundation mission of education i.e., the accurate and reliable transmission of knowledge.

References

1. S. Gupta, S. Tiwari, M. Arya, N. Kumar and R. Jain, "AdaptLearn AI: A Generative AI Framework for Bidirectional Personalization in Education," 2025 International Conference on Computing, Intelligence, and Application (CIACON), Durgapur, India, 2025, pp. 1-6, doi: 10.1109/CIACON65473.2025.11189627.
2. J. Zhu and L. Fu, "The Latest Innovations and Dilemmas in AI Empowering Personalized Education," 2025 5th International Conference on Artificial Intelligence and Education (ICAIE), Suzhou, China, 2025, pp. 245-249, doi: 10.1109/ICAIE64856.2025.11158694
3. S. AboulEla, P. Zabihitari, N. Ibrahim, M. Afshar and R. Kashef, "Exploring RAG Solutions to Reduce Hallucinations in LLMs," 2025 IEEE International systems Conference (SysCon), Montreal, QC, Canada, 2025, pp. 1-8, doi: 10.1109/SysCon64521.2025.11014810.
4. H. Elkiran and J. Rasheed, "EvaRAG: Evaluating Advanced RAG Techniques with Indexing and Distance Metrics," in IEEE Access, vol. 13, pp. 215724-215747, 2025, doi: 10.1109/ACCESS.2025.3646665
5. L. M. Oliva-Córdova, I. Álvarez-Icaza and C. E. George-Reyes, "Evaluation of Generative AI Use to Foster Critical Thinking in Higher Education," in IEEE Revista Iberoamericana de Tecnologias del Aprendizaje, vol. 20, pp. 237-243, 2025, doi: 10.1109/RITA.2025.3597848.
6. X. He, C. Liu and L. Chu, "Research and Practice on the Innovative Teaching Model of “Four-in-One” Linking “Three Educations”," 2025 6th International Conference on Modern Education and Information Management (ICMEIM), Hefei, China, 2025, pp. 78-81, doi: 10.1109/ICMEIM66684.2025.11307030.
7. S. Kukreja, T. Kumar, V. Bharate, A. Purohit, A. Dasgupta and D. Guha, "Vector Databases and Vector Embeddings-Review," 2023 International Workshop on Artificial Intelligence and Image Processing (IWAIIP), Yogyakarta, Indonesia, 2023, pp. 231-236, doi: 10.1109/IWAIIP58158.2023.10462847.
8. J. M. Smith, "AI in Computer Science Education: Tool, Subdomain, and Wildcard," 2024 47th MIPRO ICT and Electronics Convention (MIPRO), Opatija, Croatia, 2024, pp. 1267-1271, doi: 10.1109/MIPRO60963.2024.10569335.
9. Y. Wang, Y. Liang, Z. Shen and L. Guo, "Building and Implementing a Human-AI Synergistic Education-Research Ecosystem Through Multi-Agent Collaboration," 2025 5th International Conference on Artificial Intelligence and Education (ICAIE), Suzhou, China, 2025, pp. 314-317, doi: 10.1109/ICAIE64856.2025.11158579.
10. Kostopoulos, V. Gkamas, M. Rigou and S. Kotsiantis, "Agentic AI in Education: State of the Art and Future Directions," in IEEE Access, vol. 13, pp. 177467-177491, 2025, doi: 10.1109/ACCESS.2025.3620473

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Original Article

Pharmacological Properties of Selected Medicinal Plants

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Abstract

Medicinal plants have played a vital role in healthcare systems worldwide for centuries. Traditional systems such as Ayurveda and Traditional Chinese Medicine rely extensively on plant-based remedies. These plants contain bioactive phytochemicals responsible for various pharmacological activities. The present paper discusses the pharmacological properties of selected medicinal plants including Azadirachta indica (Neem), Ocimum sanctum (Tulsi), Curcuma longa (Turmeric), Aloe vera, and Withania somnifera (Ashwagandha). These plants exhibit antimicrobial, anti-inflammatory, antioxidant, antidiabetic, hepatoprotective, and anticancer activities. Scientific studies increasingly support their traditional uses.

Introduction

Medicinal plants are natural sources of therapeutic agents and are widely used in both traditional and modern medicine. They contain various phytochemicals such as alkaloids, flavonoids, tannins, glycosides, terpenoids, and phenolic compounds. These bioactive constituents are responsible for their pharmacological effects. In recent years, there has been growing interest in herbal medicine due to increasing drug resistance, adverse effects of synthetic drugs, and the need for affordable healthcare. Pharmacological studies help validate traditional claims and explore new therapeutic applications of medicinal plants.

1. Azadirachta indica (Neem)

Family: Meliaceae

Neem is one of the most important medicinal plants in India and is widely used in traditional medicine.

Pharmacological Properties

Antibacterial Activity

Neem extracts show activity against various Gram-positive and Gram-negative bacteria.

Antifungal Activity

Neem oil and leaf extracts inhibit fungal growth.

Antimalarial Activity

Traditionally used in the management of malaria; certain compounds interfere with parasite development.

Anti-inflammatory Activity

Reduces inflammation by inhibiting inflammatory mediators.

Antidiabetic Activity

Helps reduce blood glucose levels and improves insulin sensitivity.

Active Constituents

Azadirachtin, nimbin, nimbolide, quercetin.

2. Ocimum sanctum (Tulsi)

Family: Lamiaceae

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Tulsi is considered a sacred plant in India and is widely used for respiratory and immune-related disorders.

Pharmacological Properties

Antioxidant Activity

Protects cells from oxidative stress by neutralizing free radicals.

Antimicrobial Activity

Effective against bacteria, viruses, and fungi.

Adaptogenic Property

Helps the body adapt to stress and reduces anxiety.

Anti-inflammatory Activity

Inhibits inflammatory enzymes and cytokines.

Immunomodulatory Effect

Enhances immune function and resistance to infections.

Active Constituents

Eugenol, ursolic acid, rosmarinic acid, flavonoids.

3. Curcuma longa (Turmeric)

Family: Zingiberaceae

Turmeric is widely used as a spice and medicinal herb.

Pharmacological Properties

Anti-inflammatory Activity

Curcumin suppresses inflammatory pathways.

Antioxidant Activity

Scavenges free radicals and enhances antioxidant enzymes.

Anticancer Potential

Research indicates inhibition of tumor cell growth.

Hepatoprotective Effect

Protects liver cells from toxins.

Antimicrobial Activity

Effective against various microorganisms.

Active Constituent

Curcumin (major bioactive compound).

4. Aloe vera

Family: Asphodelaceae

Aloe vera is commonly used in dermatology and gastrointestinal disorders.

Pharmacological Properties

Wound Healing Activity

Promotes collagen synthesis and skin regeneration.

Anti-inflammatory Activity

Reduces redness and swelling.

Antioxidant Activity

Contains vitamins and phenolic compounds.

Laxative Effect

Aloin present in latex acts as a stimulant laxative.

Antidiabetic Activity

Improves glycemic control in some studies.

Active Constituents

Aloin, aloe-emodin, polysaccharides.

5. Withania somnifera (Ashwagandha)

Family: Solanaceae

Ashwagandha is an important medicinal herb known for its rejuvenating properties.

Pharmacological Properties

Adaptogenic Activity

Reduces stress and cortisol levels.

Neuroprotective Activity

Improves memory and cognitive function.

Anti-inflammatory Activity

Inhibits pro-inflammatory mediators.

Anticancer Potential

Withanolides show anti-proliferative effects.
Immunomodulatory Activity
Enhances immune response.
Active Constituents
Withanolides, sitoindosides, alkaloids.

Discussion

The selected medicinal plants demonstrate diverse pharmacological activities supported by experimental and clinical studies. Their effects are mainly due to bioactive phytochemicals that act through multiple biochemical pathways. Despite promising results, challenges such as standardization of extracts, dosage determination, safety evaluation, and large-scale clinical trials remain important. Integration of traditional knowledge with modern pharmacology can lead to the development of novel drugs and safer therapeutic alternatives.

Conclusion

Medicinal plants such as Neem, Tulsi, Turmeric, Aloe vera, and Ashwagandha possess significant pharmacological properties including antimicrobial, anti-inflammatory, antioxidant, antidiabetic, hepatoprotective, and anticancer activities. Scientific validation of these plants supports their traditional use and highlights their importance in future drug development. Further research and clinical studies are necessary to ensure their safety and efficacy.

References

1. Biswas, K., Chattopadhyay, I., Banerjee, R. K., & Bandyopadhyay, U. (2002). Biological activities and medicinal properties of neem (Azadirachta indica). Current Science, 82(11), 1336–1345.
2. Cohen, M. M. (2014). Tulsi – Ocimum sanctum: A herb for all reasons. Journal of Ayurveda and Integrative Medicine, 5(4), 251–259.
3. Hewlings, S. J., & Kalman, D. S. (2017). Curcumin: A review of its effects on human health. Foods, 6(10), 92.
4. Surjushe, A., Vasani, R., & Saple, D. G. (2008). Aloe vera: A short review. Indian Journal of Dermatology, 53(4), 163–166.
5. Mirjalili, M. H., et al. (2009). Steroidal lactones from Withania somnifera. Molecules, 14(7), 2373–2393.
6. World Health Organization. (2013). WHO Traditional Medicine Strategy 2014–2023. Geneva: WHO Press.

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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)

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- National Institute of Hydrology
- 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

- Compilation of data from reports published in the last 10 years (2014–2024)
- Comparison with Bureau of Indian Standards (BIS) and World Health Organization (WHO) water quality guidelines
- 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

- **Untreated Sewage:** A major contributor in urban areas.
- **Industrial Effluents:** Discharge of chemicals and heavy metals.
- **Agricultural Runoff:** Use of fertilizers and pesticides raises nitrate levels in water.
- **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

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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.

References

1. Central Pollution Control Board (2020). Water Quality Assessment Report.
2. Kumar, A., Gupta, R., & Sharma, P. (2019). Water quality status of the Yamuna River. Environmental Monitoring Journal, 12(3).
3. Ministry of Environment, Forest and Climate Change (2022). State of Environment Report. Government of India.
4. Sharma, V., & Singh, K. (2018). Groundwater contamination in North India: Nitrate and Fluoride issues. Geoscience Today, 5(2).
5. Singh, N. (2020). Effects of water contamination on public health in rural India. Health and Environment Journal, 8(1).
6. World Health Organization (2017). Guidelines for Drinking-Water Quality.

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Original Article

Comparative Analysis of Leaf Epidermal Features and Stomatal Diversity in Selected Angiospermic Plants

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Abstract

Stomata are specialized epidermal structures responsible for regulating gaseous exchange, transpiration, and photosynthesis in plants. The present study documents stomatal diversity and leaf morphological characteristics in selected angiospermic species commonly found in India. Fourteen plant species were studied through microscopic examination of leaf epidermal peels. Anisocytic, paracytic, diacytic, anomocytic, and actinocytic stomata were recorded. Most species exhibited hypostomatic leaves, indicating adaptive significance in reducing water loss. The study emphasizes the taxonomic and ecological importance of stomatal characteristics.

Keywords: *Angiosperms, Leaf anatomy, Stomatal types, Plant morphology*

Introduction

Stomata are microscopic pores present primarily on the epidermis of leaves and young stems that regulate the exchange of gases between plants and their environment. They play a central role in controlling transpiration, the uptake of carbon dioxide for photosynthesis, and the release of oxygen. The structure, distribution, and density of stomata are highly variable among plant species and are influenced by both genetic and environmental factors. Such anatomical characteristics not only reflect the physiological efficiency of a plant but also provide valuable information about its ecological adaptations.

Leaf morphology, including epidermal cell arrangement and stomatal types, is often conserved within plant families, making it an important parameter in taxonomic classification. The study of stomatal types and leaf epidermal features can, therefore, serve as a reliable tool for systematic botany, plant identification, and phylogenetic studies. Moreover, stomatal characteristics are closely linked to a plant's ability to adapt to diverse environmental conditions such as light intensity, humidity, and water availability.

Microscopic analysis of leaf epidermis provides a practical approach to documenting stomatal diversity and leaf anatomy. Several researchers have reported significant variations in stomatal types — such as anisocytic, paracytic, diacytic, anomocytic, and actinocytic — across different plant taxa, highlighting their taxonomic and ecological importance. By combining morphological observations with anatomical data, researchers can gain a better understanding of the physiological performance and adaptive strategies of plants.

The present study aims to provide a comparative analysis of stomatal diversity and leaf epidermal features in selected angiospermic plants commonly found in tropical and subtropical regions of India. This study not only documents the microscopic characteristics of these species but also explores their functional significance in relation to water regulation, photosynthetic efficiency, and ecological adaptation. Such research is important for plant anatomy education, as well as for practical applications in taxonomy, horticulture, and environmental physiology.

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Materials And Methods

1 Materials Required

- Fresh leaves of selected angiosperm plants
- Forceps
- Fine needle or scalpel
- Clean glass slides
- Cover slips
- Dropper
- Glycerine
- Distilled water
- Compound microscope
- Blotting paper or tissue paper

2. Method of Epidermal Peel Preparation

Fresh and mature leaves were selected for the study and washed thoroughly with distilled water to remove surface dust and contaminants. A small portion of the leaf was gently torn, and the epidermal layer was carefully peeled manually by hand using fine forceps**,** without the use of chemical treatments. The obtained peel was immediately transferred to a clean glass slide containing a drop of glycerine to prevent drying.

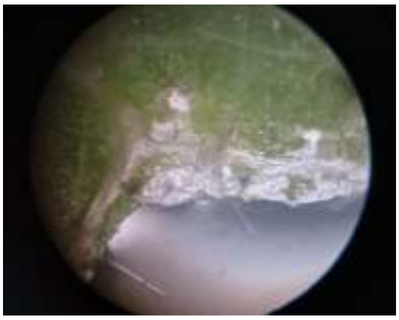
The epidermal peel was gently spread on the slide to avoid folding and covered with a cover slip. Excess mounting medium was removed using blotting paper. Prepared slides were observed under a compound microscope at suitable magnifications (10× and 40× objectives). Stomatal types were identified based on the arrangement of guard cells and subsidiary cells.

This manual peeling technique provided clear epidermal impressions, allowing accurate observation of stomatal structure and distribution.

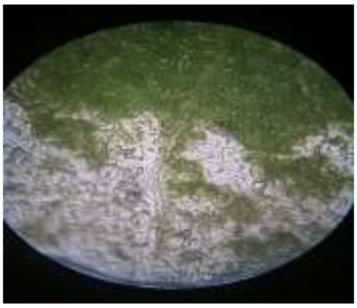
Results

1 Microscopic Observations of Individual Plant Species

Solanum melongena (Brinjal): Microscopic observation of the leaf epidermis revealed the presence of anisocytic stomata**.** Each stoma was surrounded by three subsidiary cells, one of which was distinctly smaller than the other two. The guard cells were kidney-shaped and contained chloroplasts. Stomata were predominantly located on the abaxial surface, indicating a hypostomatic leaf condition. This arrangement suggests efficient regulation of transpiration and gas exchange.



Hibiscus rosa-sinensis (China rose): The epidermal peel showed paracytic stomata, characterized by two subsidiary cells arranged parallel to the guard cells. The guard cells were reniform and clearly visible under magnification. Stomata were more numerous on the lower epidermis, supporting controlled transpiration in this evergreen ornamental shrub.



Mentha spicata (Mint): Microscopic analysis revealed diacytic stomata**,** where two subsidiary cells were positioned at right angles to the guard cells. Numerous glandular trichomes were also observed near the stomata. The leaves were

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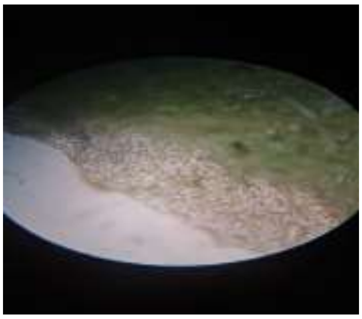
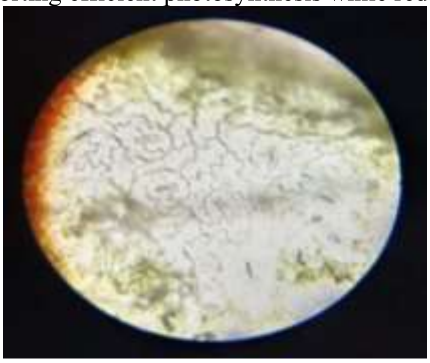
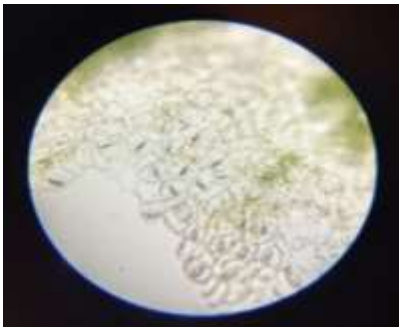
amphistomatic, with stomata present on both surfaces, facilitating high rates of gaseous exchange necessary for aromatic oil synthesis.



Ocimum tenuiflorum (Tulsi): The leaf epidermis showed predominantly diacytic stomata**,** a characteristic feature of the Lamiaceae family. Guard cells were kidney-shaped and responsive to environmental changes. Stomata were more concentrated on the lower surface, supporting efficient photosynthesis while reducing excessive water loss.



Psidium guajava (Guava): Observation revealed anisocytic stomata with three unequal subsidiary cells. The leaves were hypostomatic, with stomata confined mainly to the lower epidermis. This structural feature aids in maintaining water balance under semi-arid conditions.



Vinca rosea (Periwinkle): The epidermal peel showed **paracytic stomata**, with subsidiary cells aligned parallel to the guard cells. The uniform arrangement contributes to efficient gaseous exchange and supports the plant's ability to flower continuously throughout the year.

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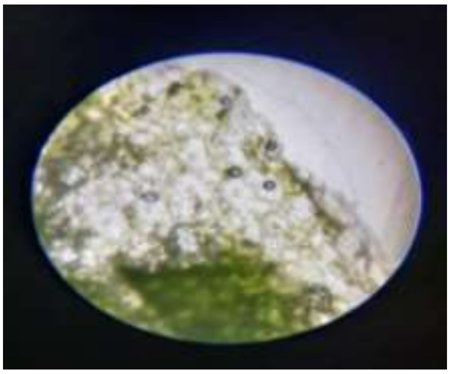
Epipremnum aureum (Money plant): Microscopic observation revealed paracytic stomata predominantly on the lower epidermis. The guard cells were moderately sized, and stomatal density was relatively low, reflecting adaptation to shaded and humid environments.



Colocasia esculenta (Cocoyam): The leaf epidermis exhibited **anomocytic stomata**, where stomata were surrounded by ordinary epidermal cells without distinct subsidiary cells. The hypostomatic nature of the leaf supports efficient gas exchange in humid habitats.

Murraya koenigii (Curry leaf): Microscopy revealed **anomocytic stomata** with irregularly arranged surrounding epidermal cells. The stomata were confined mainly to the lower epidermis, aiding in transpiration regulation under tropical conditions.

Coffea arabica (Coffee): The leaf epidermis showed well-defined paracytic stomata, typical of the Rubiaceae family. Subsidiary cells assisted in controlled opening and closing of the stomatal pore, essential for optimal photosynthesis in shaded plantation environments.

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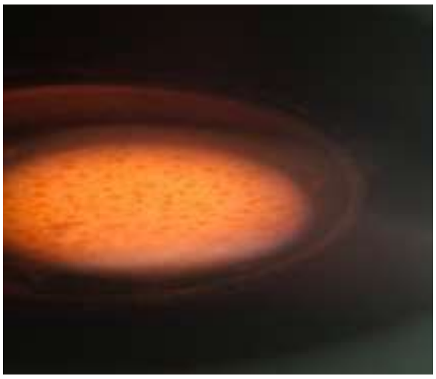
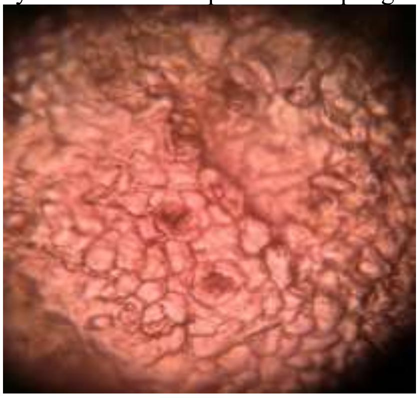
Bougainvillea spectabilis: Microscopic examination revealed anisocytic stomata**,** characterized by three unequal subsidiary cells. The hypostomatic leaf condition and reduced stomatal density support drought tolerance.



Saussurea obvallata (Brahma Kamal): The epidermis exhibited anisocytic stomata, an adaptation suited to high-altitude conditions. The unequal subsidiary cells and thick epidermis help regulate transpiration in alpine environments.



Sauropus androgynus: The leaf epidermis showed paracytic stomata with clearly defined subsidiary cells. This arrangement facilitates efficient gas exchange, supporting rapid vegetative growth.

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Piper betle (Betel leaf): Microscopic observation revealed actinocytic stomata**,** characterized by a rosette-like arrangement of subsidiary cells around the guard cells. This specialized structure aids in effective transpiration control in humid conditions.

3.2 Comparative Table of Stomatal Characteristics

Sl. No.	Plant Name	Family	Type of Stomata	Leaf Surface
1	Solanum melongena	Solanaceae	Anisocytic	Hypostomatic
2	Hibiscus rosa-sinensis	Malvaceae	Paracytic	Hypostomatic
3	Mentha spicata	Lamiaceae	Diacytic	Amphistomatic
4	Ocimum tenuiflorum	Lamiaceae	Diacytic	Hypostomatic
5	Psidium guajava	Myrtaceae	Anisocytic	Hypostomatic
6	Vinca rosea	Apocynaceae	Paracytic	Hypostomatic
7	Epipremnum aureum	Araceae	Paracytic	Hypostomatic
8	Colocasia esculenta	Araceae	Anomocytic	Hypostomatic
9	Murraya koenigii	Rutaceae	Anomocytic	Hypostomatic
10	Coffea arabica	Rubiaceae	Paracytic	Hypostomatic
11	Bougainvillea spectabilis	Nyctaginaceae	Anisocytic	Hypostomatic
12	Saussurea obvallata	Asteraceae	Anisocytic	Hypostomatic
13	Sauropus androgynus	Phyllanthaceae	Paracytic	Hypostomatic
14	Piper betle	Piperaceae	Actinocytic	Hypostomatic

Discussion

The present investigation reveals considerable diversity in stomatal structure and leaf epidermal characteristics among the selected angiospermic plants. Such variations are closely linked to taxonomic identity, ecological adaptation, and physiological requirements of the species. Stomatal type, distribution, and associated epidermal features are known to remain relatively constant within families, making them valuable diagnostic characters in plant anatomy and systematics.

The predominance of hypostomatic leaves observed in the majority of the studied species suggests an adaptive mechanism to regulate transpiration efficiently. Localization of stomata mainly on the abaxial surface reduces direct exposure to sunlight and wind, thereby minimizing excessive water loss. This feature is particularly advantageous in tropical and semi-arid environments where many of the studied plants naturally occur. Similar observations have been reported in earlier anatomical studies, emphasizing the ecological significance of hypostomatic leaf conditions.

The occurrence of anisocytic and paracytic stomata in several dicotyledonous species further supports their taxonomic relevance. Anisocytic stomata, characterized by three unequal subsidiary cells, are commonly associated with families such as Solanaceae and Myrtaceae, while paracytic stomata are typical of Malvaceae, Rubiaceae, and Apocynaceae. The consistent presence of these stomatal patterns within related taxa highlights their usefulness in anatomical classification and phylogenetic studies.

Members of the Lamiaceae family exhibited diacytic stomata, which are known to facilitate rapid opening and closing of the stomatal pore. This characteristic is functionally significant for aromatic plants such as *Mentha spicata* and *Ocimum tenuiflorum*, where efficient gaseous exchange is essential for high metabolic activity and essential oil production. The association of glandular trichomes with stomata in these species further enhances their physiological efficiency.

Anomocytic stomata observed in species such as *Colocasia esculenta* and *Murraya koenigii* represent a relatively simple stomatal organization lacking distinct subsidiary cells. This structural arrangement appears well suited to plants growing in humid or shaded habitats, where regulation of transpiration does not require highly specialized stomatal control. Similarly, the presence of actinocytic stomata in *Piper betle* indicates a specialized adaptation that supports efficient transpiration and gas exchange in warm and humid environments.

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The variations in stomatal architecture observed in the present study underline the role of environmental factors such as light intensity, humidity, and water availability in shaping leaf epidermal features. The integration of microscopic observations with ecological interpretation enhances the understanding of plant adaptive strategies. Moreover, such qualitative anatomical studies provide a foundation for future quantitative analyses, including stomatal density and stomatal index measurements, which could further strengthen ecological and physiological interpretations.
Overall, the findings of this study reaffirm the importance of stomatal characteristics as reliable indicators of plant adaptation, taxonomy, and functional efficiency. The results are consistent with classical anatomical descriptions and contribute additional observational data on commonly occurring angiospermic plants.

Conclusion

The present study provides a comprehensive comparative account of leaf morphology and stomatal diversity in selected angiospermic plants. Microscopic examination revealed significant variation in stomatal types such as anisocytic, paracytic, diacytic, anomocytic, and actinocytic stomata, which are closely associated with taxonomic affiliation and ecological adaptation. The predominance of hypostomatic leaves among the studied species indicates an adaptive strategy to minimize excessive water loss, particularly under tropical and semi-arid environmental conditions.
The occurrence of specialized stomatal arrangements in certain plant families highlights the functional efficiency of stomata in regulating transpiration and gaseous exchange. Aromatic plants exhibited stomatal features that support high metabolic activity, while drought-tolerant and shade-loving species showed structural modifications suited to their habitats. These observations confirm the significance of stomatal characters as reliable anatomical markers in plant identification and classification.

Overall, the study contributes valuable baseline data to plant anatomy and taxonomy and can serve as a reference for further physiological, ecological, and systematic studies. The integration of microscopic observations with photographic documentation enhances the scientific validity of the work and provides scope for future quantitative analysis such as stomatal index and density measurements.

References

1. Esau, K. (1977). Anatomy of Seed Plants. John Wiley & Sons, New York.
2. Metcalfe, C. R., & Chalk, L. (1950). Anatomy of the Dicotyledons. Oxford University Press, London.
3. Fahn, A. (1990). Plant Anatomy. Pergamon Press, Oxford.
4. Pandey, B. P. (2010). Plant Anatomy. S. Chand & Company, New Delhi.
5. Eames, A. J., & MacDaniels, L. H. (1947). An Introduction to Plant Anatomy. McGraw-Hill, New York.
6. Cutter, E. G. (1978). Plant Anatomy: Cells and Tissues. Edward Arnold, London.
7. Taiz, L., Zeiger, E., Møller, I. M., & Murphy, A. (2015). Plant Physiology and Development. Sinauer Associates, Sunderland, MA.
8. Mauseth, J. D. (2014). Botany: An Introduction to Plant Biology. Jones & Bartlett Learning, USA.
9. Dickison, W. C. (2000). Integrative Plant Anatomy. Academic Press, San Diego.
10. Willmer, C., & Fricker, M. (1996). Stomata. Springer Science & Business Media, London.
11. Raven, P. H., Evert, R. F., & Eichhorn, S. E. (2013). Biology of Plants. W. H. Freeman and Company, New York.
12. Metcalfe, C. R. (1983). Anatomy of the Monocotyledons. Oxford University Press, Oxford.

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Original Article

Plant Science in the Era of Climate Change: Physiological, Molecular and Agro-ecological Perspectives with Special Reference to India

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Abstract

Climate change represents one of the most critical challenges to plant science in the twenty-first century, exerting profound effects on plant growth, development, productivity, and distribution. Rising global temperatures, altered precipitation regimes, increased frequency of extreme weather events, and elevated atmospheric carbon dioxide concentrations have significantly influenced physiological and biochemical processes in plants. These changes pose serious threats to global food security, ecosystem stability, and agricultural sustainability, particularly in climate-vulnerable regions such as India. The present review critically examines the impacts of climate change on plant systems with a focus on physiological, molecular, and agro ecological responses. Emphasis is placed on abiotic stress factors such as heat, drought, salinity, and flooding, which adversely affect photosynthesis, phenology, and yield stability in major crops. The review further explores molecular mechanisms underlying stress tolerance, including stress signaling pathways, antioxidant defense systems, and stress-responsive gene expression. Indian crop-specific case studies involving rice, wheat, and pulses are discussed to highlight regional vulnerabilities and adaptive strategies. Translational botany approaches, integrating laboratory research with field-level applications, including climate-resilient breeding and climate-smart agriculture, are also reviewed. The paper concludes by identifying key research gaps and future priorities for strengthening plant resilience under changing climatic conditions. This synthesis aims to provide valuable insights for researchers, agronomists, and policymakers working toward sustainable agricultural development in the era of climate change.

Keywords: *Climate change; Abiotic stress tolerance; Translational botany; Climate-resilient agriculture*

Introduction

Climate change has emerged as one of the most significant global challenges affecting plant systems, agricultural productivity, and ecosystem stability. Rising temperatures, altered precipitation patterns, increased frequency of extreme climatic events, and elevated atmospheric CO_2 levels have collectively influenced plant growth, development, and distribution across the globe (IPCC, 2023; Lobell & Gourdji, 2012). Plants, being sessile organisms, are particularly vulnerable to environmental fluctuations and therefore rely on complex physiological and molecular mechanisms to cope with stress conditions. In India, climate variability has had pronounced effects on major crops such as rice, wheat, maize, and pulses, threatening food security and farmer livelihoods (Kumar et al., 2014). Understanding plant responses to climate change is therefore essential for developing adaptive strategies to ensure sustainable agricultural production.

Methodology of Review

The present review is based on an extensive survey of peer-reviewed literature retrieved from reputed scientific databases including Web of Science, Scopus, Google Scholar, and PubMed.

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Reports published by international organizations such as the Intergovernmental Panel on Climate Change (IPCC) and the Food and Agriculture Organization (FAO) were also consulted. Emphasis was placed on recent publications (2010–2023) focusing on plant physiological, biochemical, molecular, and agronomic responses to climate change, with special reference to Indian agro-climatic conditions.

Climate Change Impacts on Plant Systems

Temperature stress, drought, salinity, and flooding are major abiotic stresses intensified by climate change, leading to reduced photosynthetic efficiency, impaired nutrient uptake, and yield instability in crops (Hatfield & Prueger, 2015; Zhao et al., 2017). Elevated temperatures disrupt enzyme activities and membrane stability, resulting in reduced biomass accumulation and reproductive failure. Drought stress limits water availability, leading to stomatal closure, reduced carbon assimilation, and oxidative stress in plants (Reynolds et al., 2016). Salinity stress affects ion homeostasis and metabolic processes, while flooding leads to hypoxic conditions that impair root respiration and nutrient absorption (FAO, 2018).

Indian Climate and Crop Case Studies

India's agricultural systems are highly vulnerable to climate variability due to their dependence on monsoon rainfall, diverse agro-climatic zones, and the predominance of smallholder farming. Rising temperatures, increased frequency of heat waves, erratic rainfall patterns, prolonged droughts, and episodic flooding have significantly affected crop productivity and stability across different regions of the country (Kumar et al., 2014; IPCC, 2023). Cereal crops such as rice and wheat are particularly sensitive to temperature stress. In wheat-growing regions of northern and central India, terminal heat stress during grain filling accelerates senescence and reduces grain weight, leading to substantial yield losses (Lobell & Gourdji, 2012; Zhao et al., 2017). In rice-growing areas, elevated night temperatures and flooding events negatively affect grain quality and increase susceptibility to lodging and disease.

Rainfed crops, including pulses and oilseeds, are increasingly exposed to moisture stress due to irregular rainfall distribution. Drought conditions result in flower drop, poor pod development, and reduced yields. In contrast, coarse cereals and millets such as sorghum and pearl millet exhibit greater tolerance to high temperatures and low water availability, highlighting their importance as climate-resilient crops under future climate scenarios. Plant science–based adaptation strategies, including physiological screening, improved agronomic practices, and climate-smart crop management, have been instrumental in mitigating climate-induced yield losses. A comparative overview of major Indian crops, dominant climate stressors, and corresponding adaptation approaches is summarized in **Table 1**, emphasizing the role of integrative plant science in enhancing agricultural resilience.

Table 1. Climate Change Impacts, Adaptation Strategies and Affected Regions of Major Indian Crops.

Crop	**Climate Stress Factor**	**Major Physiological / Yield Impact**	**Key Adaptation Strategy**	**Major Affected Regions in India**	**Reference**
Rice (*Oryza sativa*)	High temperature, erratic rainfall	Spikelet sterility, reduced grain filling	Heat-tolerant varieties, alternate wetting and drying (AWD) irrigation	Odisha, West Bengal, Assam, Eastern Uttar Pradesh	Kumar et al., 2014
Wheat (*Triticum aestivum*)	Terminal heat stress	Reduced grain weight and shortened grain-filling period	Early sowing, heat-resilient cultivars	Punjab, Haryana, Western Uttar Pradesh, Madhya Pradesh	Challinor et al., 2014
Pulses	Drought and heat stress	Reduced nodulation and seed set	Drought-tolerant genotypes, improved water management	Maharashtra, Rajasthan, Telangana	Singh et al., 2016
Maize (*Zea mays*)	Heat and moisture stress	Reduced photosynthetic efficiency and biomass	Stress-tolerant hybrids, adjusted sowing time	Karnataka, Andhra Pradesh, Bihar	Dwivedi et al., 2016
Millets	Climate variability	Yield stability under stress conditions	Promotion of climate-resilient crops and traditional varieties	Semi-arid regions of Maharashtra, Karnataka, Rajasthan	FAO, 2018

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The inclusion of region-specific impacts and adaptation strategies highlights the translational relevance of plant science research for Indian agriculture. Such integrative approaches are essential for developing climate-resilient cropping systems and ensuring food security under changing climatic scenarios.

Molecular and Physiological Adaptations

Plants have evolved a range of molecular and physiological mechanisms to cope with climate-induced stresses. Stress perception and signal transduction involve phytohormones such as abscisic acid, salicylic acid, and jasmonates, which regulate stress-responsive gene expression (Khan et al., 2019). Antioxidant defense systems, including enzymatic and non-enzymatic components, play a crucial role in mitigating oxidative damage under stress conditions. Advances in genomics and transcriptomics have facilitated the identification of stress-tolerant genes and quantitative trait loci, enabling marker-assisted selection and genetic engineering approaches for crop improvement (Reynolds et al., 2016).

Translational Botany: From Lab to Field

Translational botany focuses on bridging the gap between laboratory-based discoveries and field-level agricultural applications. Advances in plant stress physiology, molecular breeding, and genomics have facilitated the development of climate-resilient crop varieties. In India, several success stories demonstrate the effectiveness of translational approaches in addressing climate challenges. A notable example is the development and dissemination of the Submergence-tolerant rice variety 'Subhangi Dhan', which has been introduced for flood-prone regions. This variety incorporates submergence tolerance traits that enable plants to survive prolonged inundation, thereby reducing yield losses during flash floods. The development of such varieties is based on physiological screening and molecular identification of stress-responsive traits, followed by field validation under farmers' conditions. This exemplifies how basic research on stress tolerance mechanisms can be translated into practical solutions for climate-resilient agriculture. The integration of traditional breeding with modern tools such as marker-assisted selection, genome editing, and high-throughput phenotyping has further strengthened translational botany efforts. Climate-smart agricultural practices, when combined with stress-tolerant varieties, offer sustainable solutions to mitigate the adverse impacts of climate change on Indian agriculture (FAO, 2018).

Research Gaps and Future Directions

Despite significant advances, several research gaps remain in understanding plant responses to climate change. There is a need for long-term, multi-location studies to assess genotype–environment interactions under variable climatic conditions. Greater emphasis on underutilized crops and indigenous knowledge systems can contribute to diversified and resilient agricultural systems. Strengthening interdisciplinary research and policy support will be critical for translating scientific knowledge into effective climate adaptation strategies.

Conclusion

Climate change poses unprecedented challenges to plant systems and agricultural sustainability. A comprehensive understanding of physiological, molecular, and agro-ecological responses of plants to climate stress is essential for developing resilient cropping systems. Integrating translational botany approaches with climate-smart agricultural practices offers a viable pathway to mitigate the adverse impacts of climate change, particularly in vulnerable regions such as India. Continued research and innovation in plant science will play a pivotal role in ensuring food security and environmental sustainability in the era of climate change.

References

1. **Challinor, A. J.,** Watson, J., Lobell, D. B., Howden, S. M., Smith, D. R., & Chhetri, N. (2014). A meta-analysis of crop yield under climate change and adaptation. Nature Climate Change, 4, 287–291. https://doi.org/10.1038/nclimate2153
2. **Dwivedi, S. L.,** Ceccarelli, S., Blair, M. W., Upadhyaya, H. D., Are, A. K., & Ortiz, R. (2016). Landrace germplasm for improving yield and abiotic stress adaptation. Advances in Agronomy, 138, 1–62. https://doi.org/10.1016/bs.agron.2016.03.005
3. **FAO.** (2018). Climate-smart agriculture sourcebook. Food and Agriculture Organization of the United Nations, Rome.
4. **Hatfield, J. L., & Prueger, J. H.** (2015). Temperature extremes: Effect on plant growth and development. Weather and Climate Extremes, 10,4–10 https://doi.org/10.1016/j.wace.2015.08.001
5. **IPCC.** (2023). Climate change 2023: Synthesis report. Intergovernmental Panel on Climate Change, Geneva.
6. **Khan, M. I. R.,** Fatma, M., Per, T. S., Anjum, N. A., & Khan, N. A. (2019). Salicylic acid–induced abiotic stress tolerance and underlying mechanisms in plants. Frontiers in Plant Science, 10, 1016. https://doi.org/10.3389/fpls.2019.01016
7. **Kumar, S. N.,** Aggarwal, P. K., Rani, S., Jain, S., Saxena, R., & Chauhan, N. (2014). Impact of climate change on crop productivity in India. Current Science, 106(12), 1705–1712.

8. **Lobell. B.,** & Gourdji, S. M. (2012). The influence of climate change on global crop productivity. *Plant Physiology*, 160(4), 1686–1697. https://doi.org/10.1104/pp.112.208298
9. **Raza, A.,** Razzaq, A., Mehmood, S. S., Zou, X., Zhang, X., Lv, Y., & Xu, J. (2019). Impact of climate change on crops adaptation strategies. Plant Physiology and Biochemistry, 141, 1–11. https://doi.org/10.1016/j.plaphy.2019.05.011
10. **Reynolds, M.,** Tattaris, M., Cossani, C. M., Ellis, M., Yamaguchi-Shinozaki, K., & Pierre, C. (2016). Exploring genetic resources to increase adaptation of wheat to climate change. Journal of Experimental Botany, 67(18), 5523–5538. https://doi.org/10.1093/jxb/erw330
11. **Singh, R. P.,** Singh, P. K., Rutkoski, J., Hodson, D. P., He, X., Jørgensen, L. N., Hovmøller, M.S., & Huerta-Espino, J. (2016) Disease impact on wheat yield potential and prospects of genetic control. Annual Review of Phytopathology, 54, 303–322. https://doi.org/10.1146/annurev-phyto-080615-095835
12. **Zhao, C.,** Liu, B., Piao, S., Wang, X., Lobell, D. B., Huang, Y., Huang, M., Yao, Y., Bassu, S., Ciais, P., Durand, J. L., Elliott, J., Ewert, F., Janssens, I. A., Li, T., Lin, E., Liu, Q., Martre, P., Müller, C.,& Asseng, S.(2017).Temperature increase reduces global yields of major crops. Proceedings of the National Academy of Sciences*,* 114(35), 9326–9331. https://doi.org/10.1073/pnas.1701762114

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Original Article

IOT and sensors based Portable soil tester for agriculture

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Abstract

This project presents an innovative IoT-based Portable Soil Tester designed to optimize agricultural practices. The device measures key soil parameters such as Nitrogen (N), Phosphorus (P), Potassium (K), pH, temperature, and moisture levels. The measured data is displayed on an LCD screen and transmitted to a mobile app via Wi-Fi connectivity, utilizing Arduino Uno as the core processing unit. The IoT-based Portable Soil Tester enables farmers to monitor soil health remotely, receive real-time updates, and make informed decisions about fertilizer application, irrigation, and crop selection. This technology promotes sustainable farming practices, reduces waste, and increases crop yields.

The mobile app provides a user-friendly interface for farmers to access soil data, receive alerts, and monitor crop health. By leveraging this IoT-based solution, farmers can improve agricultural productivity, reduce costs, and contribute to global food security. The Portable Soil Tester is a valuable tool for modern agriculture, enabling farmers to make data-driven decisions and adopt environmentally friendly practices. This innovative technology has the potential to transform the agricultural sector, promoting sustainability and productivity.

Keywords*: IOT, Sustainability, Arduino Uno, Portable Soil Tester*

Introduction

Automation has played a transformative role in agriculture in recent years, improving efficiency, productivity, and decision-making. Among the many factors influencing successful farming, soil quality stands as a crucial component, as it provides essential nutrients required for healthy crop growth. Soil can be categorized into three primary textures: sand, silt, and clay. While sand is commonly used in construction, silt and clay are more suitable for agriculture due to their ability to retain nutrients and moisture. However, improper identification of soil type and inadequate knowledge of nutrient content can lead to poor crop selection and, ultimately, crop failure.

With the growing number of young farmers and individuals entering the agricultural sector with limited experience, there is a need for simple and effective tools that help in understanding soil characteristics quickly. This has led to the development of the Portable Mobile Soil Tester for Agriculture, a smart, user-friendly device that enables instant analysis of soil type and its nutrient suitability. This system is designed to measure vital soil parameters such as pH, phosphorus, ammonia, and nitrate levels. These nutrients are classified into primary and secondary nutrients, both essential for maintaining soil texture and fertility. By using sensors connected to an Arduino-based system, the device provides real-time data, which is displayed in a mobile device via Bluetooth.

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Additionally, the system incorporates ThingSpeak for cloud-based data logging, battery power for field portability, and a buzzer alert system for quick notifications when nutrient levels fall outside ideal ranges. This innovative solution empowers farmers—especially new entrants—to make informed decisions, improve crop yield, and promote sustainable farming practices.

Materials and Methodology

Hardware Arduino uno, NPK Sensor, PH sensor, LCD Display, ESP8266 Wi-Fi, Power Supply, Connecting Wires, Temperature Sensor, Moisture Sensor are required.

The methodology adopted for developing the Portable Soil Tester involves several sequential steps to ensure efficiency, portability, and user-friendliness. The development approach integrates both hardware and software to offer a complete IoT-based soil analysis solution.

1 System Design Planning:

The first stage was to identify the core objective: build a low-cost, field-deployable system for real-time soil testing.

The key parameters to measure were selected based on their agricultural relevance:

- Soil pH
- Moisture content
- Temperature
- Macronutrients (NPK: Nitrogen, Phosphorus, Potassium)

These are critical indicators of soil health and fertility.

Circuit Design and Wiring:

- All components were prototyped on a breadboard and later transferred to a compact PCB.
- Analog sensors were connected to analog input pins (A0-A5) of Arduino.
- Digital modules (Wi-Fi and buzzer) used digital I/O pins.
- The LCD was interfaced using I2C protocol to save pin usage.
- Power regulation circuits ensured stable voltage for sensors and microcontroller

IoT Integration and Data Visualization:

- ESP8266 was configured in station mode using AT commands.
- Data was formatted and sent to:
- **Blynk App:** to display values on a smartphone dashboard
- **ThingSpeak**: for real-time cloud storage and data analytics
- Live graphs and parameter history could be viewed remotely from any location.

Field Testing and Validation:

- The complete unit was tested in **controlled lab environments** and then **deployed in actual field conditions.**
- Soil samples from multiple plots were tested.
- Results were verified with manual soil kits/lab testing.

Results and Discussions:

Procedure

This section outlines the step-by-step procedure for designing, assembling, coding, testing, and deploying the Portable Soil Tester for Agriculture. Each step ensures the accurate functioning and usability of the device under field conditions.

Step 1: Planning and Design

Define the problem scope, i.e., to build a low-cost soil testing device that gives real-time feedback to farmers. List out the parameters to be measured: pH, NPK (Nitrogen, Phosphorus, Potassium), temperature, and moisture. Design a functional block diagram with all required components, communication methods (Wi-Fi/Bluetooth), and display/output mechanisms (LCD and buzzer).

Step 2: Component Collection

Procure the required hardware and software tools including: Arduino Uno, pH sensor, NPK sensor, soil moisture sensor, temperature sensor (DS18B20), ESP8266 Wi-Fi module, LCD display, buzzer, connecting wires, breadboard or PCB, battery or USB power supply, Arduino IDE software, Blynk App (Android/iOS), and ThingSpeak cloud platform account.

Step 3: Circuit Connection

BbConnect analog sensors to Arduino analog pins (A0–A3), LCD via I2C, ESP8266 to digital pins with level shifter, buzzer to D10, and temperature sensor to D2. Ensure shared GND and proper regulated power supply (5V/3.3V).

Step 4: Code Development (Embedded C)

Write and upload code using Arduino IDE. Include libraries for LCD, Wi-Fi, and sensors. Structure code to read sensors, trigger buzzer on abnormal values, display on LCD, and send data to Blynk and ThingSpeak.

Step 5: Wi-Fi and App Configuration

Configure Blynk app and ThingSpeak. Insert Blynk token, ThingSpeak API key, Wi-Fi SSID and password into Arduino code.

Step 6: Sensor Calibration

Calibrate pH sensor with buffer solutions. Test moisture sensor in different soil conditions. Validate NPK sensor against known samples. Compare temperature sensor with thermometer.

Step 7: Real-Time Data Transmission

On power-up, device connects to Wi-Fi and transmits data to LCD, Blynk App, and ThingSpeak. Buzzer alerts when parameters are out of safe range.

Step 8: Testing and Deployment

Test indoors, then deploy in fields. Insert sensors, check readings, monitor Blynk app, and verify ThingSpeak data logging.

Step 9: Final Packaging and Field Use

Enclose system in waterproof case. Secure sensors. Provide USB charging point and power switch for easy field deployment.

Step 10: User Instructions

Power on the device, insert sensors into soil, view data on LCD or phone, and recharge after extended use.

Circuit Diagram:

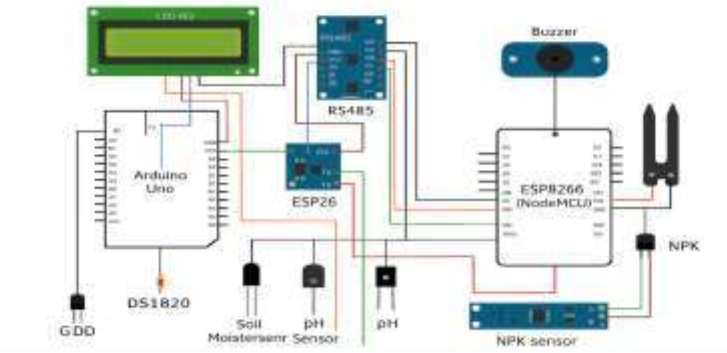

Figure 1. Circuit diagram of portable soil tester

3. Software Requirements

Arduino IDE:

The Arduino Integrated Development Environment (IDE) is the official software used to write, edit, and upload code (called sketches, saved as .ino files) to Arduino boards. It features a text editor, message area, console, toolbar, and menus. The editor supports cut/paste and find/replace functions. The message area provides feedback during saving or exporting, while the console displays error messages and system output. The toolbar allows users to verify, upload, open/save sketches, and launch the serial monitor. The bottom right shows the selected board and COM port, enabling smooth communication with connected Arduino hardware.

The IDE environment is mainly distributed into five sections

1. File
2. Edit
3. Sketch
4. Tools
5. Help

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File:
- New Creates a new instance of the editor, with the bare minimum structure of a sketch already in place.
- Open Allows to load a sketch file browsing through the computer drives and folders.
- Open Recent Provides a short list of the most recent sketches, ready to be opened.
- Sketchbook Shows the current sketches within the sketchbook folder structure; clicking on any name opens the corresponding sketch in a new editor instance.
- Examples Any example provided by the Arduino Software (IDE) or library shows up in this menu item. All the examples are structured in a tree that allows easy access by topic or library.
- Close Closes the instance of the Arduino Software from which it is clicked.
- Save Saves the sketch with the current name. If the file hasn't been named before, a name will be provided in a "Save as." window.
- Save as... Allows to save the current sketch with a different name.
- Page Setup It shows the Page Setup window for printing.
- Print Sends the current sketch to the printer according to the settings defined in Page Setup.
- Preferences Opens the Preferences window where some settings of the IDE may be customized, as the language of the IDE interface.
- Quit Closes all IDE windows. The same sketches open when Quit was chosen will be automatically reopened the next time you start the IDE.

Edit
- Undo/Redo Goes back of one or more steps you did while editing; when you go back, you may go forward with Redo.
- Cut Removes the selected text from the editor and places it into the clipboard.
- Copy Duplicates the selected text in the editor and places it into the clipboard.
- Copy for Forum Copies the code of your sketch to the clipboard in a form suitable for posting to the forum, complete with syntax coloring.
- Copy as HTML Copies the code of your sketch to the clipboard as HTML, suitable for embedding in web pages.
- Paste Puts the contents of the clipboard at the cursor position, in the editor.
- Select All Selects and highlights the whole content of the editor.
- Comment/Uncomment Puts or removes the // comment marker at the beginning of each selected line.
- Increase/Decrease Indent Adds or subtracts a space at the beginning of each selected line, moving the text one space on the right or eliminating a space at the beginning.
- Find Opens the Find and Replace window where you can specify text to search inside the current sketch according to several options.
- Find Next Highlights the next occurrence - if any - of the string specified as the search item in the Find window, relative to the cursor position.
- Find Previous Highlights the previous occurrence - if any - of the string specified as the search item in the Find window relative to the cursor position.

Sketch
- Verify/Compile Checks your sketch for errors compiling it; it will report memory usage for code and variables in the console area.
- Upload Compiles and loads the binary file onto the configured board through the configured Port.
- Upload Using Programmer This will overwrite the bootloader on the board; you will need to use Tools > Burn Bootloader to restore it and be able to Upload to USB serial port again. However, it allows you to use the full capacity of the Flash memory for your sketch. Please note that this command will NOT burn the fuses. To do so a Tools -> Burn Bootloader command must be executed.
- Export Compiled Binary Saves a .hex file that may be kept as archive or sent to the board using other tools.
- Show Sketch Folder Opens the current sketch folder.
- Include Library Adds a library to your sketch by inserting #include statements at the start of your code.
- Add File... Adds a supplemental file to the sketch (it will be copied from its current location). The file is saved to the data subfolder of the sketch, which is intended for assets such as documentation. The contents of the data folder are not compiled, so they do not become part of the sketch program.

Tools
- Auto Format This formats your code nicely: i.e. indents it so that opening and closing curly braces line up, and that the statements inside curly braces are indented more.

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- Archive Sketch Archives a copy of the current sketch in .zip format. The archive is placed in the same directory as the sketch.
- Fix Encoding & Reload Fixes possible discrepancies between the editor char map encoding and other operating systems char maps.
- Serial Monitor Opens the serial monitor window and initiates the exchange of data with any connected board on the currently selected Port. This usually resets the board, if the board supports Reset over serial port opening.
- Board Select the board that you're using.
- Port This menu contains all the serial devices (real or virtual) on your machine. It should automatically refresh every time you open the top-level tools menu.
- Programmer For selecting a hardware programmer when programming a board or chip and not using the onboard USB-serial connection.
- Burn Bootloader The items in this menu allow you to burn a bootloader onto the microcontroller on an Arduino board. This is not required for normal use of an Arduino board but is useful if you purchase a new ATmega microcontroller (which normally come without a bootloader). Ensure that you've selected the correct board from the Boards menu before burning the bootloader on the target board. This command also set the right fuses.

Help

Here you find easy access to a number of documents that come with the Arduino Software (IDE). You have access to Getting Started, Reference, this guide to the IDE and other documents locally, without an internet connection. The documents are a local copy of the online ones and may link back to our online website.

- Find in Reference This is the only interactive function of the Help menu: it directly selects the relevant page in the local copy of the Reference for the function or command under the cursor.

Uploading of code in Arduino IDE:

Before uploading a sketch in the Arduino IDE, select the correct Board and Port from the Tools menu.
On Windows, ports are usually named COM4, COM5, COM7, etc.
On Mac, ports may appear as /dev/tty. usbmodem241 or similar.
On Linux, they may appear as /dev/ttyUSBx or /dev/ttyACMx.

Once selected, click the Upload button or choose Sketch > Upload**.** Modern Arduino boards auto-reset and start uploading. On older boards (like pre-Diecimila), press the reset button manually before uploading. During upload**,** RX/TX LEDs blink, and the IDE will confirm success or show an error.

When you upload a sketch, the Arduino bootloader **i**s used—a small program preloaded onto the microcontroller. It enables uploading code without extra hardware. The bootloader becomes active briefly after a reset and then runs the last uploaded sketch. As it starts, the on-board LED (pin 13) blinks to indicate it's ready.

We have identified a suitable implementation model that consists of different sensor devices and other modules, their functionalities are shown in figure. In this implementation model we used ATMEGA 328 with Wi-Fi module. Inbuilt ADC and Wi-Fi module connects the embedded device to internet. Sensors are connected to Arduino UNO board for monitoring; ADC will convert the corresponding sensor reading to its digital value and from that value the corresponding environmental parameter will be evaluated. After sensing the data from different sensor devices, which are placed in particular area of interest. The sensed data will be automatically sent to the mobile app (blynk iot), when a proper connection is established with sever device. The sensed data will store in Thing speak for the future updation.

Figure. 3 Real time analysis of Soil testing

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The Portable Soil Tester was successfully developed and tested. The device accurately measured key soil parameters such as pH, moisture, nitrate, ammonia, and phosphorus levels. The data was read by the sensors, processed by the Arduino Uno (ATMEGA 328), and transmitted via Wi-Fi to the Blynk IoT mobile application.

All readings were also sent to ThingSpeak, allowing for real-time cloud storage and historical data analysis. The buzzer function worked well to alert the user when any parameter was beyond the acceptable range. The system operated on battery power, making it portable and suitable for field use.

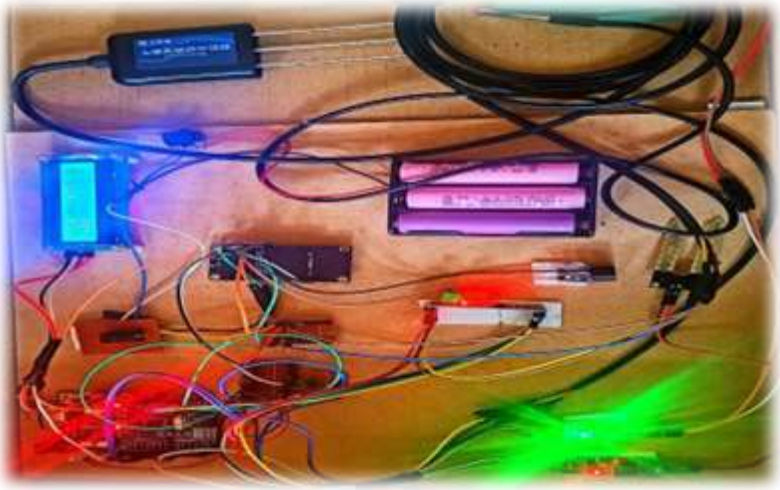

Figure. 3 Real time circuit setup of portable soil tester

Conclusion:

The project demonstrates that a low-cost, portable soil testing device can be effectively used for real-time monitoring of important soil nutrients. With the integration of Wi-Fi, ThingSpeak, and the Blynk IoT app, the system provides a smart and accessible solution for farmers to understand soil health on the spot. The inclusion of a buzzer alert and mobile connectivity improves usability and responsiveness, especially for farmers in rural or remote areas. This device can help reduce overuse of fertilizers, improve crop yields, and support sustainable farming practice.

References

1. Aitken, R.L.; Moody, P.W.; Mckinley, P.G. "Lime requirement of acidic Queensland soils. I. Relationships between soil properties and pH buffer capacity". Australian Journal of Soil Research (1990). Retrieved 5 June 2017.
2. Griffin, G., Jokela, W., Ross, D., Pettinelli, D., Morris, T., and Wolf, A. Chapter 4: Recommended Soil Nitrate Tests. Recommended Soil Testing Procedures for the Northeastern United States (2009). \
3. Will Brinton-The Curious Case of Soil pH -A dynamic view of acidity management in farming-November -2019.
4. Jianhan Lin, Maohua Wang*, Miao Zhang, Yane Zhang, Li Chen, Electrochemical sensors For Soil Nutrient Detection: Opportunity and Challenge, pp 1362-67.
5. McLean, E.O in “Methods of Soil Analysis”, Part 2, Agron. 9, AL. Page, RH. Miller, & D.R. Keeney (Eds), Am. Soc. Agron., Madison, WI, pp. (1982).
6. Joaquin Gutierrez jaguey, Juan Francisco villa-medina, Aracely Lopez- Guzman, and Miguel Angel PortaGandara 2.
7. Samira A. Ben Mussa, Hawaa S. Elferjani, Faiza A. Haroun, Fatma F. Abdelnabi “Determination of Available Nitrate, Phosphate and Sulfate in Soil Samples”, International Journal of PharmTech Research

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Original Article

Multipurpose Robotic Vehicle for Smart Agriculture and Fire Safety

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Abstract

The increasing demand for automation in agriculture and public safety has accelerated the development of multifunctional robotic systems capable of operating in hazardous and labor-intensive environments. This work presents the design, theoretical analysis, implementation, and experimental validation of a multipurpose robotic vehicle intended for smart agricultural operations and fire safety applications. The proposed robotic platform integrates grass cutting, pesticide spraying, and fire detection with extinguishing mechanisms into a single mobile unit controlled through an ESP32-based embedded system. A rigorous theoretical framework involving DC motor dynamics, power consumption modeling, and sensor response characteristics is employed to justify component selection and operational reliability. Wireless control combined with real-time video monitoring enables safe remote operation, significantly reducing human exposure to pesticides and fire-prone environments. Experimental investigations demonstrate efficient grass cutting, uniform pesticide distribution, and rapid-fire detection and suppression. The system exhibits stable communication, acceptable power efficiency, and robust mechanical performance. The proposed solution is cost-effective, modular, and scalable, making it suitable for smart farming practices and emergency response scenarios.

Keywords: *Multipurpose robot, smart agriculture, fire safety, ESP32, automation, embedded systems*

Introduction

Agriculture and public safety sectors are currently experiencing a significant paradigm shift driven by rapid advancements in automation, robotics, and embedded systems. Conventional agricultural practices such as grass cutting and pesticide spraying continue to rely predominantly on manual labor, making these operations labor-intensive, time-consuming, and inefficient, particularly for large-scale agricultural fields. Moreover, prolonged human involvement in such activities exposes workers to serious occupational hazards. Continuous exposure to chemical pesticides has been widely associated with adverse health effects, including respiratory disorders, skin diseases, and long-term neurological complications. Similarly, manual grass cutting requires sustained physical effort, leading to fatigue and reduced productivity while increasing operational costs.

Firefighting and public safety operations present even greater challenges due to their inherently hazardous nature. Fire incidents expose personnel to extreme temperatures, toxic gases, smoke inhalation, and unpredictable structural failures. In many cases, delayed response or limited access to hazardous zones can result in severe property damage and loss of life. These risks highlight the critical need for technological interventions capable of reducing direct human involvement while improving response efficiency and operational safety.

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Robotic systems have emerged as an effective alternative to traditional manual methods by enabling remote or semi-autonomous execution of dangerous, repetitive, and physically demanding tasks. Advances in embedded systems, sensor technologies, and wireless communication have significantly enhanced the capabilities of robotic platforms. Sensors provide real-time environmental feedback, actuators enable precise mechanical operations, and wireless modules facilitate remote monitoring and control. As a result, robots can operate in environments that are unsafe or inaccessible to humans, thereby improving safety and reliability.

Over the past decade, extensive research efforts have been directed toward the development of agricultural robots and firefighting robots as separate domains. Agricultural robots have been designed for tasks such as mowing, spraying, monitoring, and harvesting, while firefighting robots focus on flame detection, navigation, and extinguishing mechanisms. Despite these advancements, most existing robotic systems are designed to perform a single function. This single-purpose approach increases deployment costs, requires multiple dedicated systems for different applications, and results in higher maintenance and energy consumption. Furthermore, the lack of functional integration limits adaptability in environments where multiple operational requirements coexist.

The concept of a multipurpose robotic vehicle addresses these limitations by integrating multiple functionalities into a unified platform. Such systems improve resource utilization, reduce overall operational cost, and enhance flexibility across diverse application scenarios. A robotic platform capable of performing both agricultural and fire safety tasks is particularly advantageous in rural, semi-industrial, and resource-constrained regions, where the availability of manpower, equipment, and emergency services is often limited.

In this context, the present work proposes a multipurpose robotic vehicle that integrates grass cutting, pesticide spraying, and fire detection with extinguishing capabilities using a unified control architecture. The system is designed to be modular, cost-effective, and scalable, enabling seamless switching between operational modes. The primary objectives of this study are to design a reliable robotic platform, develop a theoretically supported control strategy based on motor dynamics and power analysis, and experimentally evaluate system performance under various operational conditions. The proposed approach aims to contribute toward safer, more efficient, and technologically driven solutions for smart agriculture and public safety applications.

Materials And Methods

The proposed robotic system is developed using a modular design approach, allowing each subsystem to operate independently while sharing a common control framework. The system consists of mechanical, electrical, and software subsystems coordinated by an ESP32 microcontroller. This section details the materials used and the methodology adopted for system development and testing.

The mechanical subsystem comprises a lightweight yet rigid chassis mounted on four wheels driven by DC geared motors. The chassis is designed to support the cutting mechanism, spraying unit, water reservoir, pump, sensors, and battery without compromising stability. A rotary cutting blade is mounted at the front of the vehicle for effective grass cutting, while a nozzle-based spraying mechanism is employed for pesticide application.

The electrical subsystem includes an ESP32 microcontroller, DC motors, motor driver module, flame sensor, ultrasonic sensor, water pump, spraying pump, rechargeable battery, and voltage regulation circuitry. The ESP32 is selected due to its integrated Wi-Fi capability, low power consumption, and sufficient processing speed for real-time control and sensor data processing.

The selection of DC motors is based on torque and power requirements. The torque generated by a DC motor is given by $T = K_tI$, where T represents the output torque, Kt is the torque constant, and I is the armature current. This relationship ensures that the selected motors provide sufficient torque for vehicle locomotion and grass cutting operations under load conditions.

Power consumption analysis is performed using $P = VI$, where V is the supply voltage and I is the current drawn by the system. Battery capacity is chosen to ensure continuous operation for extended periods while maintaining portability. Sensor characteristics such as detection range, sensitivity, and response time are considered to ensure reliable fire detection and obstacle avoidance.

The control strategy follows an event-driven and modular approach. User commands are transmitted wirelessly to the ESP32 microcontroller, which interprets the commands and activates the corresponding subsystems. Pulse Width Modulation (PWM) is employed to regulate motor speed and pump flow, enabling precise control over cutting and spraying operations.

Results and Discussion

The developed multipurpose robotic vehicle was subjected to comprehensive experimental evaluation under controlled laboratory and field-like conditions to assess its functional performance, reliability, and consistency across different operational modes. The experiments were designed to validate the effectiveness of the mechanical structure, electrical subsystem, control logic, and theoretical assumptions employed during system design. The primary operational modes evaluated included grass cutting, pesticide spraying, and fire detection with extinguishing, each representing a critical application domain of the proposed system.

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Grass cutting experiments were conducted on natural grass surfaces with varying densities and heights to evaluate the locomotion stability, cutting efficiency, and mechanical robustness of the robotic vehicle. The system demonstrated smooth and stable movement across uneven terrain, which can be attributed to the balanced chassis design, appropriate wheel traction, and sufficient torque generated by the DC geared motors. The robotic vehicle was able to effectively cut grass with heights reaching approximately 6 cm without noticeable reduction in speed or cutting quality.

The uniformity of the cutting operation indicates that the selected motor specifications and blade design were appropriate for the intended application. The cutting performance directly validates the theoretical torque calculations based on the relationship $T=K_tIT = Kt\ IT=K_tI$, where the motor torque was sufficient to overcome both mechanical resistance and load variations during operation. No stalling or excessive vibration was observed during extended cutting sessions, suggesting that the mechanical coupling between the motor and cutting blade was efficient and well-aligned.

Additionally, thermal observations during prolonged grass cutting operations revealed no abnormal heating of motors or drivers, indicating effective power distribution and current handling. This confirms that the power consumption estimates and component ratings were suitably matched, ensuring operational safety and durability. The results demonstrate that the robotic platform can reliably perform grass cutting tasks in small to medium agricultural fields, gardens, and institutional landscapes.

The pesticide spraying mode was evaluated to assess spray uniformity, flow control accuracy, and system responsiveness. The spraying mechanism employed a pump-based fluid delivery system controlled through PWM signals generated by the ESP32 microcontroller. Experimental observations showed consistent and uniform spray patterns across repeated trials, confirming stable pump operation and effective nozzle design.

Adjustable flow rates were successfully achieved by varying the PWM duty cycle, enabling precise control over the quantity of pesticide dispensed. This capability is particularly important for precision agriculture, where excessive pesticide usage leads to environmental pollution, increased operational costs, and potential crop damage. The ability to regulate spray intensity allows targeted application, reducing chemical wastage while maintaining effectiveness.

The integration of wireless control significantly enhanced operational flexibility. Commands issued remotely were executed promptly, with negligible communication delay. The stability of the wireless link throughout the spraying experiments demonstrates the reliability of the ESP32's communication capability under continuous operation. Even during extended spraying sessions, no loss of connectivity or unintended system behavior was observed.

From a power management perspective, the spraying pump exhibited predictable current consumption, aligning with the theoretical power analysis based on $P=VIP = VIP=VI$. The battery performance remained stable, supporting sustained spraying operations without rapid voltage drop. These observations confirm that the electrical subsystem was adequately designed to handle dynamic load variations introduced by the pump operation.

Fire detection and extinguishing experiments were conducted to evaluate the sensitivity of the flame sensor, response time of the control system, and effectiveness of the extinguishing mechanism. Controlled flame sources were introduced at varying distances and orientations to simulate real-world fire scenarios. The flame sensor consistently detected fire sources within its effective range, triggering the control logic as expected.

Upon detection, the ESP32 microcontroller processed the sensor signal and activated the water pump with minimal delay. The response time, measured from flame detection to pump activation, was sufficiently short to enable early-stage fire suppression. This rapid response is primarily influenced by the sensor sensitivity, analog signal processing speed, and efficient control algorithm implementation.

The extinguishing mechanism successfully suppressed small flames within a short duration, demonstrating the practical utility of the system for fire safety applications in agricultural storage areas, small industrial units, and residential premises. The system's ability to operate autonomously in fire detection mode reduces dependence on human intervention, thereby enhancing safety in hazardous environments.

The reliability of fire detection was further confirmed by the absence of false triggering under non-flame conditions, indicating appropriate threshold selection and noise immunity. This balance between sensitivity and stability is crucial to avoid unnecessary activation while ensuring timely response during actual fire incidents.

Wireless communication plays a critical role in the operation of the proposed robotic system, particularly for remote monitoring and control in hazardous environments. Throughout all experimental modes, the wireless connection remained stable and responsive. Commands issued by the operator were executed in real time, with no noticeable latency affecting system performance.

The reliability of wireless communication enhances the usability of the robotic vehicle in real-world applications, allowing operators to maintain a safe distance while retaining full control over system functions. The consistent performance observed during experiments confirms the suitability of the ESP32 platform for IoT-enabled robotic applications.

The experimental results strongly support the theoretical assumptions made during system design. The motor dynamics analysis accurately predicted the torque and power requirements necessary for locomotion, cutting, and

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pumping operations. The absence of mechanical failure, overheating, or power instability confirms that the theoretical models were effectively translated into practical design choices.

Sensor performance closely aligned with expected response characteristics, validating the selection of flame and ultrasonic sensors for environmental interaction. The integration of multiple subsystems did not introduce significant interference or performance degradation, highlighting the effectiveness of the modular design approach.

One of the most significant outcomes of the experimental evaluation is the successful integration of multiple functionalities into a single robotic platform without compromising individual task performance. The system efficiently transitioned between agricultural and fire safety modes, demonstrating operational flexibility and robustness.

From a practical standpoint, the system offers a cost-effective alternative to deploying multiple specialized robots. Its modular nature allows future expansion and customization, making it adaptable to evolving application requirements. The results confirm that the proposed multipurpose robotic vehicle is not only technically feasible but also practically viable for real-world deployment.

While the experimental results are promising, certain limitations were observed. The fire extinguishing mechanism is suitable for small-scale fires and may require enhancement for larger fire scenarios. Additionally, the system currently relies on manual or semi-autonomous control, which may limit efficiency in large agricultural fields. These limitations, however, do not detract from the overall effectiveness of the proposed system and instead provide clear directions for future improvements.

The comprehensive experimental evaluation demonstrates that the proposed multipurpose robotic vehicle successfully fulfills its intended objectives. The system effectively performs grass cutting, pesticide spraying, and fire detection with extinguishing, while maintaining stable wireless communication and efficient power utilization. The close agreement between theoretical analysis and experimental outcomes reinforces the validity of the design methodology adopted in this work. Overall, the results highlight the feasibility, reliability, and practical relevance of the proposed robotic platform for smart agriculture and fire safety applications.

Program Code (ESP32 – Arduino IDE)

```
#defineMOTOR_LEFT5
#defineMOTOR_RIGHT18
#definePUMP19
#defineFLAME_SENSOR34
voidsetup(){
 pinMode(MOTOR_LEFT,OUTPUT);
 pinMode(MOTOR_RIGHT,OUTPUT);
 pinMode(PUMP,OUTPUT);
 pinMode(FLAME_SENSOR,INPUT);
}
voidloop(){
 intflameValue=analogRead(FLAME_SENSOR);
 if(flameValue<1000){
  digitalWrite(PUMP,HIGH);//Firedetected
 }else{
  digitalWrite(PUMP,LOW);
 }
}
```

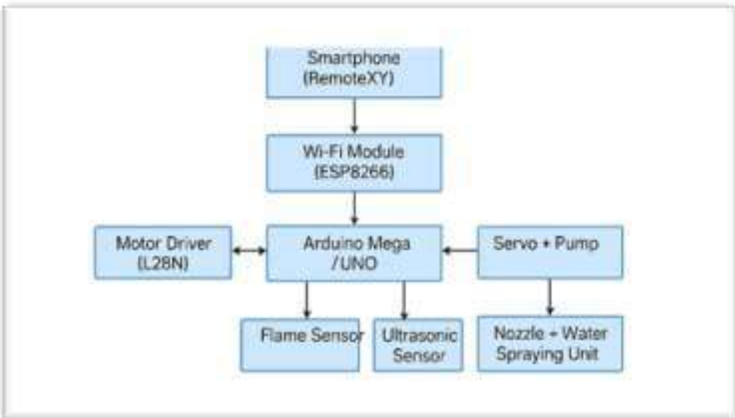

Figure 1: Block diagram illustrating the overall architecture of the multipurpose robotic vehicle

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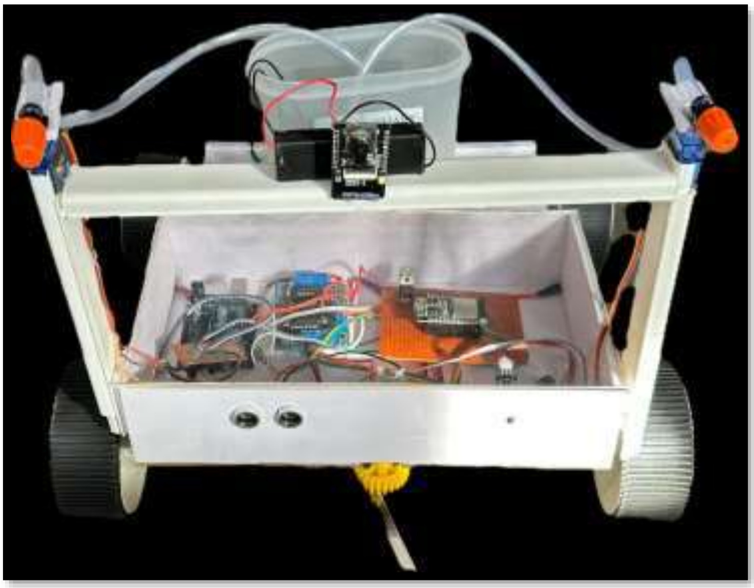

Figure 2. Photograph of the fully assembled and operational multipurpose robotic vehicle

Conclusion

This work presents the successful design, implementation, and experimental validation of a multipurpose robotic vehicle for smart agriculture and fire safety applications. By integrating grass cutting, pesticide spraying, and fire detection with extinguishing mechanisms into a unified platform, the system significantly reduces human effort and exposure to hazardous environments. Theoretical analysis supported key design decisions, while experimental results confirmed reliable and efficient performance across all operational modes. The proposed robotic system is cost-effective, modular, and scalable, making it suitable for deployment in agricultural fields, industrial premises, and emergency response scenarios. Future work may focus on autonomous navigation, artificial intelligence-based decision-making, and IoT-enabled monitoring to further enhance system intelligence and adaptability.

Reference

1. Daniel J. Pack, Robert Avanzato; David J. Ahlgren, Igor M. Verner, "Fire-Fighting Mobile Robotics and Interdisciplinary Design-Comparative Perspectives", IEEE Transactions on Education, 3 August, 2004, Volume 47
2. Kuo L. Su, "Automatic Fire Detection System Using Adaptive Fusion Algorithm for Fire Fighting Robot", Systems, Man, and Cybernetics, IEEE International Conference, 8-11 October 2006, Pages: 966-971.
3. Scott Dearie; Kevin Fisher, Brian Rajala; Steven Wasson, "Design and Construction of a Fully Autonomous Fire Fighting Robot", 2004 IEEE, Pages: 303-310.
4. Smith, J., S. Campbell, and J. Morton (2005). Design and Implementation of a Control Algorithm for an Autonomous Grass Cutter. Circuits and Systems.7-10 10 August. Midwest Symposium, 456-459.
5. Mohammad Baloch, T. and K. Timothy Thien Ching. (2008). Design and modelling a prototype of a robotic Grass Cutter Information Technology, International Symposium, 25-28 August. 1-5.
6. Hicks, R.B. and Hall, E. A Survey of Robot Grass Cutters, SPIE Intelligent Robotics and Computer Vision Conference

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Original Article

Studies of Mass Attenuation Coefficient and Effective Atomic Number of Narcotic Drugs and Medical Drugs in the Energy Range 1keV to 100GeV Using WINXCOM

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Abstract

The nature is composed of matter hence the interaction of radiation with matter is natural process. The study of absorption of gamma rays in the composite materials has become an interesting and exciting field of research. Here we have discussed about the changes that occur after interacting with radiation of different photon energy ranging from 1 keV to 100 GeV. The photon mass attenuation co-efficient, effective atomic number are the basic quantities required in determining the penetration of X ray and Gamma photons in matter. The knowledge of mass attenuation coefficient of X-rays and Gamma photons in biological chemical and other important materials of significant practical interest for industrial biological agricultural defence and medical applications.

Key words: *X- Rays, Radiation, Mass attenuation co-efficient, Effective atomic number*

Introduction

In recent years, the interaction of ionizing radiation with pharmaceutical compounds has garnered significant interest due to its implications for radiation dosimetry, shielding design, and quality control in medical imaging and therapy. Narcotic drugs, known for their psychoactive effects and complex molecular structures, alongside common medical drugs used in treatments for pain, infection, and cardiovascular conditions, exhibit unique radiological behaviors that influence photon attenuation. Theoretical computations of mass attenuation coefficients (μ/ρ) and effective atomic numbers (Z_eff)—key parameters for characterizing photon interactions like photoelectric absorption, Compton scattering, and pair production offer a reliable means to predict these properties across wide energy spectra without extensive experimental setups.

WINXCOM, a versatile software based on mixture rules and cross-section databases, enables precise calculations of these parameters from 1 keV to 100 GeV, accounting for elemental compositions derived from drug formulations. Existing studies have explored such metrics for select pharmaceuticals, revealing energy-dependent trends where low-energy dominance shifts from photoelectric effects to scattering and production processes at higher energies. This work builds on those foundations by systematically analyzing μ/ρ and Z_eff for a targeted set of narcotic and medical drugs, providing insights into their radiation response for practical applications in radiology and security screening.

Materials and Methodology:

All the medicinal drugs used are of standred pharmaceutical grade procured from medical labs.

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Computational Approach

Mass attenuation coefficients (μ/ρ) were computed using WINXCOM software (version 2020 or later), a Windows-based tool implementing XCOM photon cross-section data. Calculations spanned photon energies from 1 keV to 100 GeV in logarithmic steps (e.g., 140-150 points per decade) to capture absorption edges and interaction transitions. Mixture rule was applied as per Hubbell and Seltzer:

Results and Discussion:

1 MDMA (3,4- Methylenedioxymethamphetamine) **($C_{11}H_{15}NO_2$):**

3, 4-Methylenedioxymethamphetamine (MDMA), commonly known as ecstasy (E), is a psychoactive drug used primarily as a recreational drug. Desired effects include increased empathy, euphoria, and heightened sensations. When taken by mouth, effects begin after 30–45 minutes and last 3–6 hours. It is also sometimes snorted or smoked.[14] As of 2017, MDMA has no accepted medical uses.

Adverse effects of MDMA use include addiction, memory problems, paranoia, difficulty sleeping, teeth grinding, blurred vision, sweating, and a rapid heartbeat. Use may also lead to depression and fatigue. Deaths have been reported due to increased body temperature and dehydration. MDMA increases the release and slows the reuptake of the neurotransmitters serotonin, dopamine, and norepinephrine in parts of the brain. It has stimulant and psychedelic effects. The initial increase is followed by a short-term decrease in the neurotransmitters. MDMA belongs to the substituted methylenedioxyphenethylamine and substituted amphetamine classes of drugs.

Structural formula of MDMA

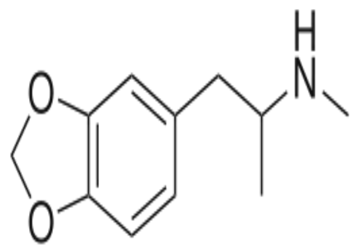

Table 1. Calculation of mass attenuation coefficient and effective atomic number of MDMA

Energy in Mev	μ/ρ of compound in gm/cm^2 theoritical	μ/ρ of compound in gm/cm^2 software	Total molecular crossection	Effective atomic crossection	Effective electronic crossection	Effective atomic number
0.001	2.33E+03	2.32E+03	8.03E-19	2.76E-20	4.20E-21	6.57E+0
0.002	3.30E+02	3.30E+03	1.14E-19	3.91E-21	5.92E-22	6.61E+0
0.003	9.97E+01	9.96E+03 4.19E+01	3.44E-20	1.18E-21	1.79E-22	6.62E+0
0.004	4.19E+01	4.00E+01	1.45E-20	4.97E-22	7.53E-23	6.61E+0
0.005	4.00E+01	1.21E+01	1.38E-20	4.73E-22	6.99E-23	6.76E+0
0.006	1.22E+01	7.54E+00	4.21E-21	1.45E-22	2.22E-23	6.51E+0
0.007	7.53E+00	5.04E+00	2.60E-21	8.93E-23	1.34E-23	6.64E+0
0.008	5.04E+00	3.53E+00	1.74E-21	5.98E-23	9.48E-24	6.30E+0
0.009	3.52E+00	2.75E+00	1.22E-21	4.18E-23	6.79E-24	6.16E+0
0.01	2.73E+00	5.03E-01	9.43E-22	3.24E-23	5.43E-24	5.97E+0
0.02	5.07E-01	2.36E-01	1.75E-22	6.02E-24	1.46E-24	4.14E+0
0.04	2.36E-01	1.99E-01	8.16E-23	2.81E-24	9.39E-25	2.99E+0
0.06	1.99E-01	1.87E-01	6.89E-23	2.37E-24	8.44E-25	2.81E+0
0.08	1.83E-01	1.73E-01 1.69E-01	6.33E-23	2.18E-24	7.90E-25	2.76E+0
0.09	1.73E-01	1.42E-01	5.97E-23	2.06E-24	7.59E-25	2.71E+0
0.1	1.69E-01	1.21E-01	5.83E-23	2.01E-24	7.41E-25	2.71E+0
0.2	1.39E-01	1.08E-01	4.81E-23	1.66E-24	6.12E-25	2.70E+0
0.3	1.21E-01	9.92E-02	4.18E-23	1.44E-24	5.32E-25	2.71E+0
0.4	1.09E-01	9.18E-02	3.75E-23	1.29E-24	4.77E-25	2.71E+0

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0.5	9.92E-02	8.56E-02	3.43E-23	1.18E-24	4.36E-25	2.71E+0
0.6	9.18E-02	8.05E-02	3.17E-23	1.09E-24	4.03E-25	2.71E+0
0.7	8.57E-02	7.61E-02	2.96E-23	1.02E-24	3.76E-25	2.71E+0
0.8	8.06E-02	7.25E-02	2.78E-23	9.59E-25	3.54E-25	2.71E+0
0.9	7.62E-02	5.08E-02	2.63E-23	9.07E-25	3.35E-25	2.71E+0
1	7.25E-02	4.05E-02	2.50E-23	8.62E-25	3.18E-25	2.71E+0
2	5.06E-02	3.46E-02	1.75E-23	6.02E-25	2.22E-25	2.72E+0
3	4.04E-02	304E-02	1.40E-23	4.81E-25	1.76E-25	2.74E+0
4	3.45E-02	2.77E-02	1.19E-23	4.10E-25	1.49E-25	2.76E+0
5	3.05E-02	2.54E-02	1.05E-23	3.63E-25	1.30E-25	2.79E+0
6	2.77E-02	2.40E-02	9.57E-24	3.30E-25	1.17E-25	2.82E+0
7	2.56E-02	2.26E-02	8.85E-24	3.05E-25	1.07E-25	2.85E+0
8	2.40E-02	2.16E-02	8.29E-24	2.85E-25	9.90E-26	2.88E+0
9	2.27E-02	1.68E-02	7.84E-24	2.70E-25	9.27E-26	2.91E+0
10	2.17E-02	1.53E-02	7.48E-24	2.57E-25	8.75E-26	2.94E+0
20	1.69E-02	1.52E-02	5.84E-24	2.01E-25	6.27E-26	3.21E+0
30	1.55E-02	1.47E-02	5.36E-24	1.85E-25	5.42E-26	3.41E+0
40	1.50E-02	1.45E-02	5.17E-24	1.78E-25	5.02E-26	3.55E+0
50	1.47E-02	1.45E-02	5.09E-24	1.75E-25	4.79E-26	3.66E+0
60	1.46E-02	1.46E-02	5.05E-24	1.74E-25	4.65E-26	3.73E+0
70	1.46E-02	1.46E-02	5.05E-24	1.74E-25	4.57E-26	3.81E+0
80	1.47E-02	1.47E-02	5.07E-24	1.74E-25	4.53E-26	3.85E+0
90	1.48E-02	1.55E-02	5.09E-24	1.75E-25	4.50E-26	3.89E+0
100	1.48E-02	1.58E-02	5.11E-24	1.76E-25	4.47E-26	3.93E+0
200	1.54E-02	1.61E-02	5.33E-24	1.84E-25	4.49E-26	4.09E+0
300	1.59E-02	1.63E-02	5.49E-24	1.89E-25	4.57E-26	4.13E+0
400	1.62E-02	1.66E-02	5.60E-24	1.93E-25	4.64E-26	4.16E+0
500	1.64E-02	1.67E-02	5.68E-24	1.95E-25	4.69E-26	4.17E+0
600	1.66E-02	1.69E-02	5.74E-24	1.97E-25	4.73E-26	4.17E+0
700	1.67E-02	1.69E-02	5.78E-24	1.99E-25	4.77E-26	4.17E+0
800	1.69E-02	1.82E-02	5.82E-24	2.00E-25	4.80E-26	4.17E+0
900	1.69E-02	1.31E-02	5.85E-24	2.01E-25	4.82E-26	4.18E+0
1000	1.83E-01	1.74E-02	6.32E-23	2.18E-24	2.03E-24	1.08E+0
1500	1.32E+00	1.75E-02	4.56E-22	1.56E-23	2.24E-24	6.94E+0
2000	1.74E-02	1.78E-02	6.01E-24	2.07E-25	4.95E-26	4.18E+0
2500	1.75E-02	1.78E-02	6.04E-24	2.08E-25	4.97E-26	4.18E+0
3000	1.76E-02	1.78E-02	6.06E-24	2.09E-25	4.99E-26	4.18E+0
3500	1.76E-02	1.78E-02	6.08E-24	2.09E-25	5.01E-26	4.18E+0
4000	1.76E-02	1.78E-02	6.09E-24	2.10E-25	5.02E-26	4.18E+0
4500	1.77E-02	1.79E-02	6.10E-24	2.10E-25	5.03E-26	4.18E+0
5000	1.77E-02	1.78E-02	6.11E-24	2.10E-25	5.04E-26	4.18E+0
6000	1.77E-02	1.78E-02	6.13E-24	2.11E-25	5.05E-26	4.17E+0
7000	1.78E-02	1.78E-02	6.14E-24	2.11E-25	5.06E-26	4.17E+0
8000	1.78E-02	1.79E-02	6.14E-24	2.11E-25	5.07E-26	4.17E+0
9000	1.78E-02	1.79E-02	6.15E-24	2.12E-25	5.07E-26	4.17E+0
		1.79E-02				
		1.79E-02				
		1.80E-02				
		1.80E-02				
		1081E-02				

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10000	1.79E-02	1.81E-02	6.17E-24	2.12E-25	5.09E-26	4.18E+0
20000	1.79E-02	1.81E-02	6.19E-24	2.13E-25	5.11E-26	4.17E+0
30000	1.79E-02	1.81E-02	6.20E-24	2.13E-25	5.11E-26	4.17E+0
40000	1.79E-02		6.20E-24	2.13E-25	5.12E-26	4.17E+0
50000	1.80E-02		6.20E-24	2.13E-25	5.12E-26	4.17E+0
60000	1.80E-02		6.21E-24	2.14E-25	5.13E-26	4.17E+0
70000	1.80E-02		6.21E-24	2.14E-25	5.13E-26	4.17E+0
80000	1.80E-02		6.21E-24	2.14E-25	5.13E-26	4.17E+0
90000	1.80E-02		6.21E-24	2.14E-25	5.13E-26	4.17E+0
100000	1.80E-02		6.21E-24	2.14E-25	5.13E-26	4.17E+0

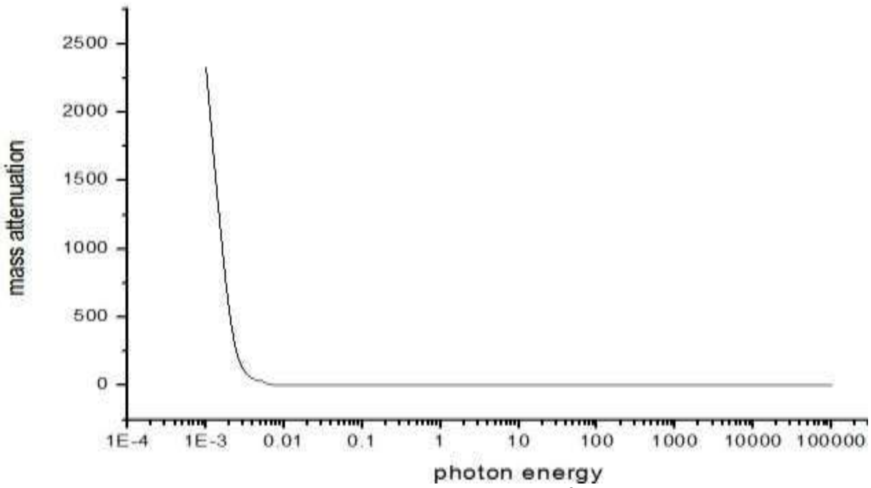

Figure.1 represents the graph of mass attenuation coefficent in gm/cm^2 v/s photon energy; i.e., as the photon energy increases the mass attenuation co efficient decreases. In other words, attenuation is less for high photon energy.

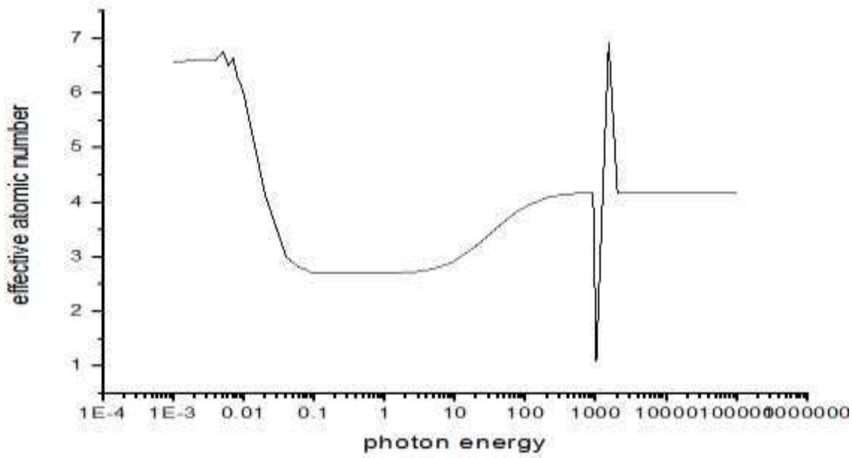

Figure. 2 represents the graph of effective atomic number v/s photon energy

Methadone ($C_{21}H_{27}NO$):

Methadone, sold under the brand name Dolophine, among others, is an opioid used to treat pain and as maintenance therapy or to help with detoxification in people with opioid dependence. Detoxification using methadone can either be done relatively rapidly in less than a month or gradually over as long as six months. While a single dose has a rapid effect, maximum effect can take five days of use. The effects last about six hours after a single dose and a day and a half after long-term use in people with normal liver function. Methadone is usually taken by mouth and rarely by injection into a muscle or vein.

Side effects are similar to those of other opioids. Commonly these include dizziness, sleepiness, vomiting, and sweating. Serious risks include opioid abuse or a decreased effort to breathe. Abnormal heart rhythms may also occur

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including prolonged QT. The number of deaths in the United States involving methadone poisoning was 4,418 in 2011, which was 26% of total deaths from opioid poisoning. Risks are greater with higher doses. Methadone is made by chemical synthesis and acts on opioid receptors.

Structural of methadone

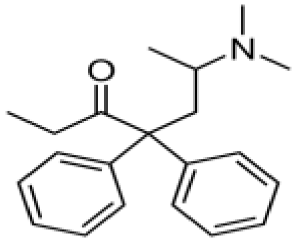

Table 2. Calculation of mass attenuation coefficient and effective atomic number of Methadone.

Energy in Mev	μ/ρ of compound in gm/cm^2	μ/ρ of compound in gm/cm^2	Total molecular cross-section	Effective atomic cross-section	Effective electronic cross-section	Effective atomic number
0.001	2015.069888	2015.07188	1.12413E-18	2.25E-20	3.62E-21	6.21283159
0.002	279.5082425	279.412425	1.55927E-19	3.12E-21	5.00E-22	6.23342809
0.003	83.66504516	83.6550451	4.66735E-20	9.33E-22	1.50E-22	6.23304697
0.004	34.97538442	34.9753835	1.95114E-20	3.90E-22	6.28E-23	6.21300804
0.005	29.32145939	29.3634593	1.63573E-20	3.27E-22	5.05E-23	6.47381175
0.006	10.11306375	10.1401637	5.64169E-21	1.13E-22	1.85E-23	6.09782101
0.007	6.22340785	6.22307892	3.4718E-21	6.94E-23	1.11E-23	6.24147812
0.008	4.17634815	4.19634346	2.32982E-21	4.66E-23	7.94E-24	5.86403545
0.009	2.92351191	2.92351169	1.63091E-21	3.26E-23	5.72E-24	5.70111978
0.01	2.286715062	2.28671530	1.27567E-21	2.55E-23	4.63E-24	5.50750813
0.02	0.45781509	0.44691509	2.55397E-22	5.08E-24	1.35E-24	3.75735203
0.04	0.233114838	0.23561483	1.30046E-22	2.58E-24	9.19E-25	2.80523497
0.06	0.200517025	0.20151709	1.11861E-22	2.22E-24	8.32E-25	2.66257771
0.08	0.185244003	0.18684413	1.03341E-22	2.05E-24	7.80E-25	2.62247963
0.09	0.175510784	0.17551408	9.79107E-23	1.94E-24	7.51E-25	2.58012642
0.1	0.171517983	0.17161793	9.56833E-23	1.89E-24	7.34E-25	2.58130904
0.2	0.141444568	0.14264456	7.89065E-23	1.56E-24	6.06E-25	2.57781674
0.3	0.123035882	0.12635896	6.8637E-23	1.36E-24	5.27E-25	2.5804755
0.4	0.110303312	0.11230332	6.1534E-23	1.22E-24	4.72E-25	2.58181209
0.5	0.100819686	0.11181968	5.62434E-23	1.11E-24	4.32E-25	2.57962083
0.6	0.093260143	0.093261340	5.20262E-23	1.03E-24	3.99E-25	2.57989176
0.7	0.087037487	0.087237423	4.85549E-23	9.61E-25	3.72E-25	2.58317716
0.8	0.081921363	0.081921356	4.57008E-23	9.05E-25	3.51E-25	2.58040422
0.9	0.07745422	0.07745784	4.32087E-23	8.55E-25	3.31E-25	2.58084993
1	0.073662782	0.073662568	4.10936E-23	8.13E-25	3.15E-25	2.58083485
2	0.051383968	0.051383023	2.86651E-23	5.67E-25	2.19E-25	2.58793759
3	0.04104113	0.041041652	2.28953E-23	4.53E-25	1.74E-25	2.60602925
4	0.034941331	0.034940452	1.94924E-23	3.86E-25	1.47E-25	2.62824339
5	0.030884778	0.03088985	1.72294E-23	3.41E-25	1.29E-25	2.65332658

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6	0.028007139	0.02808959	1.56241E-23	3.09E-25	1.15E-25	2.68049396
7	0.025847823	0.02596523	1.44195E-23	2.86E-25	1.06E-25	2.70775999
8	0.024173084	0.02425608	1.34852E-23	2.67E-25	9.77E-26	2.73529251
9	0.022850781	0.02289658	1.27476E-23	2.53E-25	9.14E-26	2.76293332
10	0.021759963	0.02175965	1.2139E-23	2.41E-25	8.62E-26	2.79015216
20	0.016812414	0.01696541	9.379E-24	1.86E-25	6.14E-26	3.03039050
30	0.015323152	0.01525836	8.5482E-24	1.70E-25	5.29E-26	3.20993296
40	0.014715662	0.01479658	8.2093E-24	1.63E-25	4.88E-26	3.34123022
50	0.014440251	0.01431589	8.05566E-24	1.60E-25	4.66E-26	3.43992469
60	0.014277099	0.01423485	7.96464E-24	1.58E-25	4.51E-26	3.51129856
70	0.014273053	0.01426589	7.96239E-24	1.58E-25	4.43E-26	3.57908163
80	0.014297101	0.01422368	7.9758E-24	1.59E-25	4.38E-26	3.62334905
100	0.014378054	0.01437894	8.02096E-24	1.60E-25	4.32E-26	3.69437912
200	0.014959121	0.01481586	8.34512E-24	1.66E-25	4.33E-26	3.84171977
300	0.01538626	0.01539806	8.5834E-24	1.71E-25	4.40E-26	3.8863705
400	0.015680127	0.01568015	8.74734E-24	1.74E-25	4.46E-26	3.90591914
500	0.015898041	0.01589856	8.86891E-24	1.77E-25	4.51E-26	3.91553671
600	0.016059885	0.01505620	8.95919E-24	1.78E-25	4.55E-26	3.92372175
700	0.016194824	0.01619035	9.03447E-24	1.80E-25	4.59E-26	3.92316603
800	0.016297085	0.01629708	9.09152E-24	1.81E-25	4.62E-26	3.91980216
900	0.016381489	0.01638148	9.1386E-24	1.82E-25	4.63E-26	3.92714662
1000	0.201643811	0.20564381	1.12489E-22	2.17E-24	2.04E-24	1.06689544
1500	0.826578489	0.82457848	4.61116E-22	9.22E-24	1.34E-24	6.89179927
2000	0.016828448	0.0168975	9.38794E-24	1.87E-25	4.76E-26	3.93025463
2500	0.016916602	0.01691652	9.43712E-24	1.88E-25	4.78E-26	3.9293293
3000	0.016983863	0.01698233	9.47464E-24	1.89E-25	4.80E-26	3.92901985
3500	0.017034339	0.01703654	9.5028E-24	1.89E-25	4.82E-26	3.92852219
4000	0.017072791	0.01706985	9.52425E-24	1.90E-25	4.83E-26	3.92818044
4500	0.017100707	0.01710235	9.53983E-24	1.90E-25	4.84E-26	3.92692033
5000	0.017129933	0.01712568	9.55613E-24	1.90E-25	4.85E-26	3.92700239
600	0.017170409	0.01717049	9.57871E-24	1.91E-25	4.86E-26	3.92566828
7000	0.017197552	0.01719752	9.59385E-24	1.91E-25	4.87E-26	3.92554236
8000	0.017215766	0.01721766	9.60401E-24	1.91E-25	4.87E-26	3.92465660
9000	0.01724898	0.0172898	9.62254E-24	1.92E-25	4.88E-26	3.92495919
10000	0.017305944	0.0175944	9.65432E-24	1.92E-25	4.89E-26	3.92839794
20000	0.017351478	0.01731478	9.67972E-24	1.93E-25	4.91E-26	3.92420002
30000	0.017363621	0.01733621	9.6865E-24	1.93E-25	4.92E-26	3.92290032
40000	0.017374335	0.01734335	9.69247E-24	1.93E-25	4.92E-26	3.92143820
50000	0.017383442	0.01733442	9.69755E-24	1.93E-25	4.93E-26	3.92100260
60000	0.017397371	0.0173771	9.70532E-24	1.93E-25	4.93E-26	3.91750121
70000	0.017397371	0.01739771	9.70532E-24	1.93E-25	4.93E-26	3.91750121
80000	0.017397371	0.01739771	9.70532E-24	1.93E-25	4.93E-26	3.91750121
90000	0.017397371	0.01739771	9.70532E-24	1.93E-25	4.93E-26	3.91750121
100000	0.017397371	0.01739771	9.70532E-24	1.93E-25	4.93E-26	3.91750121

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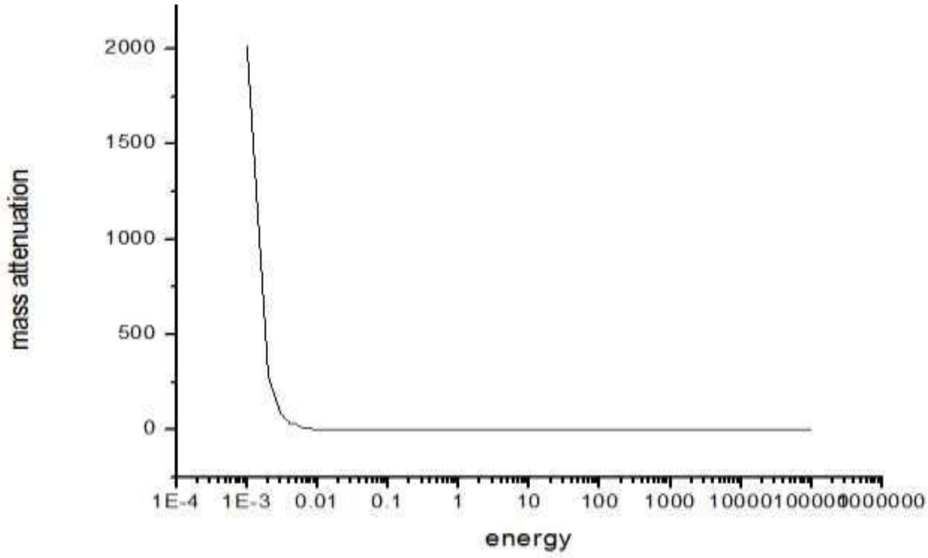

Figure. 3 represents graph of mass attenuation coefficient v/s photon energy

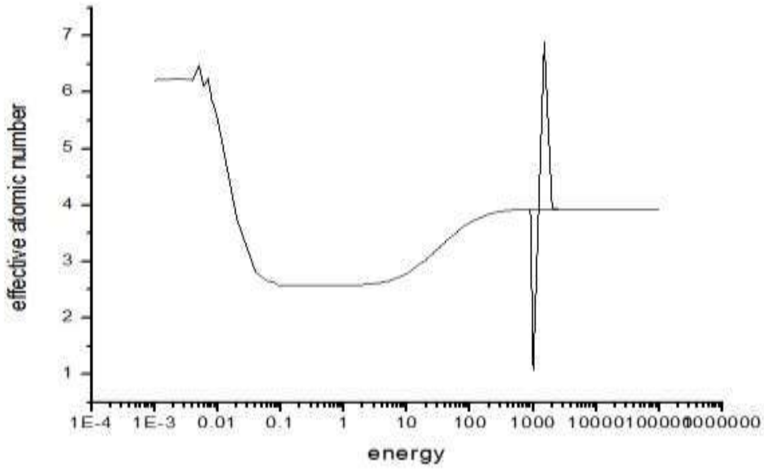

Figure. 4 represents the graph of effective atomic number v/s photon energy

Methaphetamine ($C_{10}H_{15}N_1$):

` Methamphetamine (contracted from *N*-methylamphetamine) is a strong central nervous system (CNS) stimulant that is mainly used as a recreational drug and less commonly as a treatment for attention deficit hyperactivity disorder and obesity.

In low doses, methamphetamine can elevate mood, increase alertness, concentration and energy in fatigued individuals, reduce appetite and promote (initial) weight loss. At higher doses, it can induce psychosis, breakdown of skeletal muscle, seizures and bleeding in the brain. Chronic high-dose use can precipitate unpredictable and rapid mood swings, prominent delusions and violent behavior. Recreationally, methamphetamine's ability to increase energy has been reported to lift mood and increase sexual desire to such an extent that users are able to engage in sexual activity continuously for several days. Methamphetamine is known to have a high addiction liability (i.e. compulsive methamphetamine use) and dependence liability (i.e. withdrawal symptoms occur when methamphetamine use ceases). Heavy recreational use of methamphetamine may lead to a post-acute-withdrawal syndrome, which can persist for months beyond the typical withdrawal period. Unlike amphetamine, methamphetamine is neurotoxic to human midbrain dopaminergic neurons. It has also been shown to damage serotonin neurons in the CNS. This damage includes adverse changes in brain structure and function, such as reductions in grey matter volume in several brain regions and adverse changes in markers of metabolic integrity.

Methamphetamine belongs to the substituted phenethylamine and substituted amphetamine chemical classes. It is related to the other dimethylphenethylamines as a positional isomer of these compounds, which share the common chemical formula: $C_{10}H_{15}N_1$.

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Structural of methamphetamine

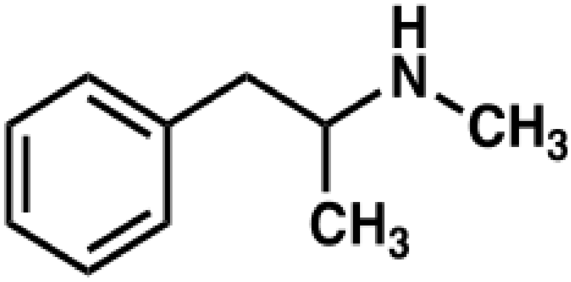

Table 3. Calculations of mass attenuation co-efficent and effective atomic number of methamphetamines.

Energy in mev	μ/ρ of compound in gm/cm^2	μ/ρ of compound in gm/cm^2	Total molecular cross-section	Effective atomic cross-section	Effective electronic cross-section	Effective atomic number
0.001	1.90E+03	1.90E+03	5.18E-19	1.98E-20	3.25E-21	6.11E+00
0.002	2.62E+02	2.62E+02	7.13E-20	2.73E-21	4.47E-22	6.12E+00
0.003	7.81E+01	7.81E+01	2.13E-20	8.15E-22	1.33E-22	6.11E+00
0.004	3.26E+01	3.22E+01	8.87E-21	3.40E-22	5.59E-23	6.08E+00
0.005	4.03E+01	4.06E+01	1.10E-20	4.18E-22	6.37E-23	6.56E+00
0.006	9.40E+00	9.45E+00	2.56E-21	9.82E-23	1.65E-23	5.94E+00
0.007	5.77E+00	5.77E+00	1.57E-21	6.03E-23	9.87E-24	6.11E+00
0.008	3.88E+00	3.88E+00	1.06E-21	4.06E-23	7.17E-24	5.65E+00
0.009	2.72E+00	2.72E+00	7.41E-22	2.84E-23	5.20E-24	5.46E+00
0.01	2.14E+00	2.13E+00	5.82E-22	2.23E-23	4.25E-24	5.25E+00
0.02	4.44E-01	4.48E-01	1.21E-22	4.63E-24	1.35E-24	3.44E+00
0.04	2.35E-01	2.36E-01	6.39E-23	2.45E-24	9.55E-25	2.57E+00
0.06	2.03E-01	2.03E-01	5.54E-23	2.13E-24	8.70E-25	2.44E+00
0.08	1.88E-01	1.88E-01	4.76E-23	1.97E-24	8.17E-25	2.41E+00
0.09	1.79E-01	1.79E-01	3.92E-23	1.87E-24	7.88E-25	2.37E+00
0.1	1.75E-01	1.75E-01	3.41E-23	1.83E-24	7.70E-25	2.37E+00
0.2	1.44E-01	1.44E-01	3.06E-23	1.51E-24	6.36E-25	2.37E+00
0.3	1.25E-01	1.28E-01	2.80E-23	1.31E-24	5.52E-25	2.37E+00
0.4	1.12E-01	1.16E-01	2.59E-23	1.17E-24	4.95E-25	2.37E+00
0.5	1.03E-01	1.05E-01	2.41E-23	1.07E-24	4.53E-25	2.37E+00
0.6	9.50E-02	9.50E-02	2.27E-23	9.93E-25	4.19E-25	2.37E+00
0.7	8.87E-02	8.87E-02	2.15E-23	9.27E-25	3.90E-25	2.37E+00
0.8	8.35E-02	8.34E-02	2.04E-23	8.72E-25	3.68E-25	2.37E+00
0.9	7.89E-02	7.89E-02	1.43E-23	8.25E-25	3.48E-25	2.37E+00
1	7.50E-02	7.50E-02	1.14E-23	7.84E-25	3.31E-25	2.37E+00
2	5.23E-02	5.27E-02	9.68E-24	5.47E-25	2.30E-25	2.38E+00
3	4.18E-02	4.18E-02	8.55E-24	4.37E-25	1.82E-25	2.39E+00
4	3.55E-02	3.56E-02	5.99E-24	3.71E-25	1.54E-25	2.41E+00
5	3.14E-02	3.14E-02	8.55E-24	3.28E-25	1.35E-25	2.44E+00
6	2.84E-02	2.84E-02	7.74E-24	2.97E-25	1.21E-25	2.46E+00
7	2.62E-02	2.62E-02	7.14E-24	2.74E-25	1.10E-25	2.49E+00

8	2.45E-02	2.45E-02	6.67E-24	2.56E-25	1.02E-25	2.51E+00
9	2.31E-02	2.31E-02	6.30E-24	2.42E-25	9.53E-26	2.54E+00
10	2.20E-02	2.21E-02	5.99E-24	2.30E-25	8.98E-26	2.56E+00
20	1.69E-02	1.69E-02	4.60E-24	1.76E-25	6.34E-26	2.78E+00
30	1.53E-02	1.53E-02	4.17E-24	1.60E-25	5.42E-26	2.95E+00
40	1.47E-02	1.49E-02	3.99E-24	1.53E-25	4.98E-26	3.08E+00
50	1.44E-02	1.44E-02	3.91E-24	1.50E-25	4.73E-26	3.17E+00
60	1.42E-02	1.42E-02	3.86E-24	1.48E-25	4.57E-26	3.24E+00
70	1.42E-02	1.42E-02	3.86E-24	1.48E-25	4.47E-26	3.31E+00
80	1.42E-02	1.42E-02	3.86E-24	1.48E-25	4.42E-26	3.35E+00
100	1.42E-02	1.42E-02	3.88E-24	1.49E-25	4.35E-26	3.42E+00
200	1.48E-02	1.48E-02	4.02E-24	1.54E-25	4.33E-26	3.57E+00
300	1.52E-02	1.52E-02	4.13E-24	1.59E-25	4.39E-26	3.61E+00
400	1.55E-02	1.52E-02	4.21E-24	1.62E-25	4.45E-26	3.63E+00
500	1.57E-02	1.57E-02	4.27E-24	1.64E-25	4.50E-26	3.64E+00
600	1.58E-02	1.58E-02	4.31E-24	1.65E-25	4.53E-26	3.65E+00
700	1.60E-02	1.60E-02	4.35E-24	1.67E-25	4.57E-26	3.65E+00
800	1.61E-02	1.61E-02	4.38E-24	1.68E-25	4.61E-26	3.64E+00
900	1.62E-02	1.62E-02	4.40E-24	1.69E-25	4.62E-26	3.65E+00
1000	2.27E-01	2.27E-01	6.18E-23	2.37E-24	2.25E-24	1.05E+00
1500	1.67E+00	1.68E+00	4.56E-22	1.73E-23	2.50E-24	6.94E+00
2000	1.66E-02	1.66E-02	4.52E-24	1.73E-25	4.74E-26	3.65E+00
2500	1.67E-02	1.67E-02	4.54E-24	1.74E-25	4.77E-26	3.65E+00
3000	1.67E-02	1.67E-02	4.56E-24	1.75E-25	4.79E-26	3.65E+00
3500	1.68E-02	1.68E-02	4.57E-24	1.75E-25	4.80E-26	3.65E+00
4000	1.68E-02	1.68E-02	4.58E-24	1.76E-25	4.81E-26	3.65E+00
4500	1.69E-02	1.69E-02	4.59E-24	1.76E-25	4.82E-26	3.65E+00
5000	1.69E-02	1.69E-02	4.60E-24	1.76E-25	4.83E-26	3.65E+00
6000	1.69E-02	1.69E-02	4.61E-24	1.77E-25	4.85E-26	3.65E+00
7000	1.70E-02	1.70E-02	4.62E-24	1.77E-25	4.85E-26	3.65E+00
8000	1.70E-02	1.70E-02	4.62E-24	1.77E-25	4.86E-26	3.65E+00
9000	1.70E-02	1.70E-02	4.63E-24	1.78E-25	4.87E-26	3.65E+00
10000	1.71E-02	1.71E-02	4.65E-24	1.78E-25	4.88E-26	3.65E+00
20000	1.71E-02	1.71E-02	4.66E-24	1.79E-25	4.90E-26	3.65E+00
30000	1.71E-02	1.71E-02	4.66E-24	1.79E-25	4.90E-26	3.65E+00
40000	1.71E-02	1.71E-02	4.67E-24	1.79E-25	4.91E-26	3.65E+00
50000	1.71E-02	1.71E-02	4.67E-24	1.79E-25	4.91E-26	3.65E+00
60000	1.72E-02	1.72E-02	4.67E-24	1.79E-25	4.92E-26	3.64E+00
70000	1.72E-02	1.72E-02	4.67E-24	1.79E-25	4.92E-26	3.64E+00
80000	1.72E-02	1.72E-02	4.67E-24	1.79E-25	4.92E-26	3.64E+00
90000	1.72E-02	1.72E-02	4.67E-24	1.79E-25	4.92E-26	3.64E+00
100000	1.72E-02	1.72E-02	4.67E-24	1.79E-25	4.92E-26	3.64E+00

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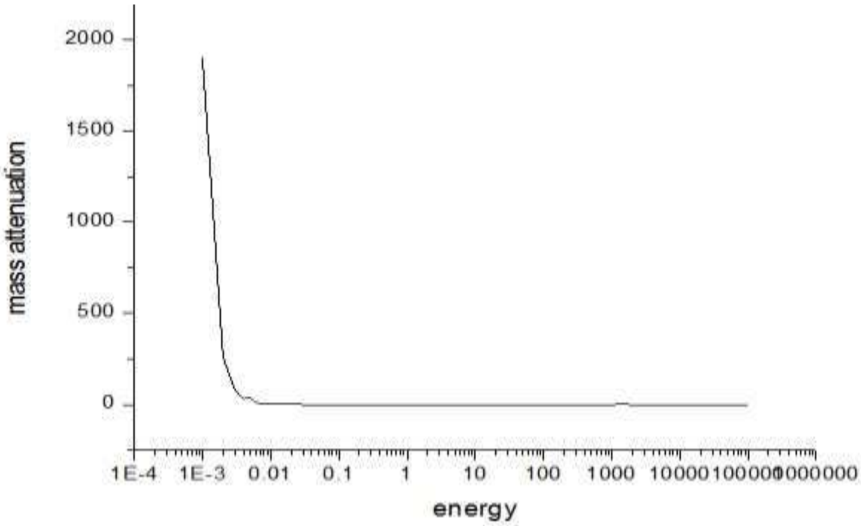

Figure 5. Represents graph of mass attenuation coefficient v/s photon energy

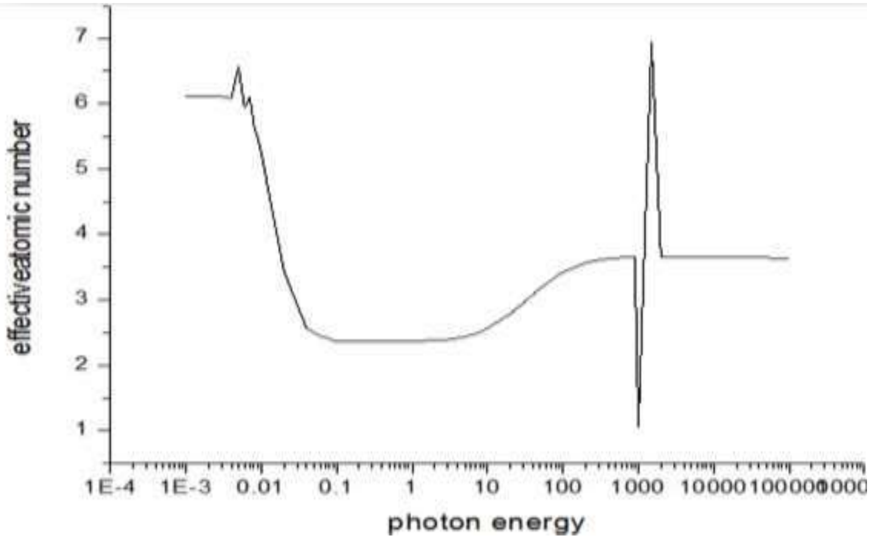

Figure. 6 represents the graph of effective atomic number v/s photon energy

Conclusion:

The mass attenuation coefficient, effective atomic number and effective electron densities of some illegal narcotic drugs like Methadone MDMA, Methamphetamine and also some medical drugs like Penicillin Tetracycline, Ampicillin are calculated by direct method considering photon interaction in wide range of energy between 1 keV-100GeV using WINXC OM and Auto Z_{eff}. We observe results of these parameters varies with energy and composition of drugs. The variations in above parameters can be observed graphically. Based on mass attenuation coefficient effective atomic number and electron densities we can detect the drugs (security purpose) and also one can get the information about purity of drugs.

References:

1. Gerward, L.; Guilbert, N.; Jensen, K. B.; Levring, H. WinXCom—A Program for Calculating X-Ray Attenuation Coefficients. Radiat. Phys. Chem. 2004, 71, 653–654. https://doi.org/10.1016/j.radphyschem.2004.04.040
2. Gaikwad, D. K.; Pawar, P. P.; Selvam, T. P. Mass Attenuation Coefficients and Effective Atomic Numbers of Biological Compounds for Gamma Ray Interactions. Radiat. Phys. Chem. 2017, 138, 75–80. https://doi.org/10.1016/j.radphyschem.2017.03.040
3. Pawar, P. P.; Bichile, G. K. Studies on Mass Attenuation Coefficient, Effective Atomic Number and Electron Density of Some Amino Acids. Radiat. Phys. Chem. 2013, 92, 22–27. https://doi.org/10.1016/j.radphyschem.2013.07.004
4. Kore, P. S.; Pawar, P. P. Measurements of Mass Attenuation Coefficient, Effective Atomic Number and Electron Density of Some Amino Acids. Radiat. Phys. Chem. 2014, 98, 86–91. https://doi.org/10.1016/j.radphyschem.2013.12.038

5. Kaur, G.; Singh, K. J.; Singh, P. Studies on Mass Attenuation Coefficients, Effective Atomic Numbers and Electron Densities for Some Biomolecules. Radiat. Phys. Chem. 2018, 153, 86–91. https://doi.org/10.1016/j.radphyschem.2018.08.025
6. Akkurt, I.; El-Khayatt, A. M. The Effect of Chemical Composition on Mass Attenuation Coefficient and Radiation Shielding Properties. Radiat. Phys. Chem. 2016, 125, 65–68. https://doi.org/10.1016/j.radphyschem.2016.03.014
7. Hubbell, J. H.; Seltzer, S. M. Tables of X-Ray Mass Attenuation Coefficients and Mass Energy-Absorption Coefficients. NIST Standard Reference Database 126. https://doi.org/10.18434/T4D01F
8. Kaewkhao, J.; Laopaiboon, J.; Chewpraditkul, W. Mass Attenuation Coefficients and Effective Atomic Numbers of Some Materials. J. Quant. Spectrosc. Radiat. Transfer 2008, 109, 1260–1265. https://doi.org/10.1016/j.jqsrt.2007.10.007
9. Singh, V. P.; Badiger, N. M. Gamma-Ray Attenuation and Shielding Parameters of Some Glass Systems. Nucl. Instrum. Methods Phys. Res., Sect. B 2012, 274, 68–73. https://doi.org/10.1016/j.nimb.2011.12.015
10. El-Khayatt, A. M. Attenuation Coefficients of Glass Systems Containing Heavy Elements. Ann. Nucl. Energy 2011, 38, 218–224. https://doi.org/10.1016/j.anucene.2010.09.010

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Original Article

Synthesis and Characterization of Conducting Polypyrrole Prepared by Chemical Oxidative Polymerization

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Abstract

Conducting polymers have attracted significant attention due to their unique combination of electrical conductivity and polymeric properties such as flexibility, lightweight nature, and corrosion resistance [1]. Among these materials, polypyrrole (PPy) is one of the most extensively studied conducting polymers because of its ease of synthesis, environmental stability, and tuneable electrical properties [2, 3]. In the present work, polypyrrole was synthesized via chemical oxidative polymerization using ferric chloride ($FeCl_3$) as an oxidizing agent. The synthesized polymer was characterized using Fourier Transform Infrared (FTIR) spectroscopy, UV–Visible absorption spectroscopy, and Scanning Electron Microscopy (SEM). Electrical properties were investigated using the two-probe method. FTIR analysis confirmed the formation of polypyrrole through characteristic vibrational bands corresponding to C–N, C–H, C=C, and N–H bonds. UV–Visible spectroscopy revealed absorption peaks associated with π–π transitions, indicating the presence of conjugated structures. SEM images showed a globular morphology with closely packed granular structures. The electrical conductivity of the synthesized polypyrrole was calculated to be 1.42×10^{-3} S cm^{-1}, confirming its semiconducting nature. These results demonstrate that chemically synthesized polypyrrole exhibits promising structural and electrical characteristics suitable for applications in sensors, corrosion protection, and electronic devices.*

Introduction

Polymers are macromolecules composed of repeating structural units known as monomers. Traditionally, polymers have been regarded as electrically insulating materials and widely used for insulation, packaging, and structural applications. However, the discovery of electrically conducting polymers revolutionized polymer science by introducing materials that combine electrical conductivity with the mechanical advantages of plastics.

The breakthrough in conducting polymers occurred in the 1970s when polyacetylene was found to exhibit high conductivity upon doping [4]. This discovery led to the development of a new class of materials known as intrinsically conducting polymers (ICPs), which include polyaniline, polythiophene, and polypyrrole. These polymers possess conjugated π-electron systems along their backbone, allowing charge transport when doped with suitable oxidizing or reducing agents [5]. However, intrinsic conductivity is low unless charge carriers are introduced through oxidation or reduction (doping) [6]. The charge carriers in most conducting polymers are polarons and bipolarons, which move through the conjugated structure via hopping mechanisms [7]. Among the conducting polymers, polypyrrole (PPy) stands out due to its environmental stability, relatively high conductivity, and simple synthesis.

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Polypyrrole is formed by the polymerization of pyrrole, a five-membered heterocyclic aromatic compound. The electrical conductivity of PPy arises from the formation of charge carriers such as polarons and bipolarons within the conjugated backbone during oxidative doping.

Despite its advantages, polypyrrole in its undoped form behaves as an insulator. Conductivity is achieved through oxidation, which introduces positive charge carriers along the polymer chain. These carriers move through the conjugated system via hopping or tunnelling mechanisms. The final electrical properties depend strongly on synthesis conditions, dopant type, and morphology.

The motivation for the present work lies in the growing importance of conducting polymers in applications such as gas sensors, energy storage devices, corrosion-resistant coatings, Biocompatibility and corrosion resistance [2,8], and environmental remediation. This study focuses on the chemical synthesis of polypyrrole using $FeCl_3$ and its structural, optical, morphological, and electrical characterization.

Materials and Methods

1 Materials

- Pyrrole (monomer)
- Ferric chloride ($FeCl_3$) as oxidizing agent
- Distilled water

All chemicals were used without further purification.

2. Synthesis of Polypyrrole

Polypyrrole was synthesized by chemical oxidative polymerization. A 1 M pyrrole solution was prepared in distilled water. Ferric chloride solution was prepared separately and used in a monomer-to-oxidant ratio of **1:2.4**. The oxidizing agent was added slowly to the pyrrole solution under constant stirring for 30 minutes at approximately 5 °C. Polymerization was allowed to proceed for 4 hours under continuous stirring. The reaction mixture was then left undisturbed for 24 hours to allow the polymer to settle. The resulting black polypyrrole precipitate was filtered and washed several times with distilled water to remove residual oxidant and by-products. The polymer was dried at room temperature for two days. The dried powder was later pressed into pellets for electrical measurements.

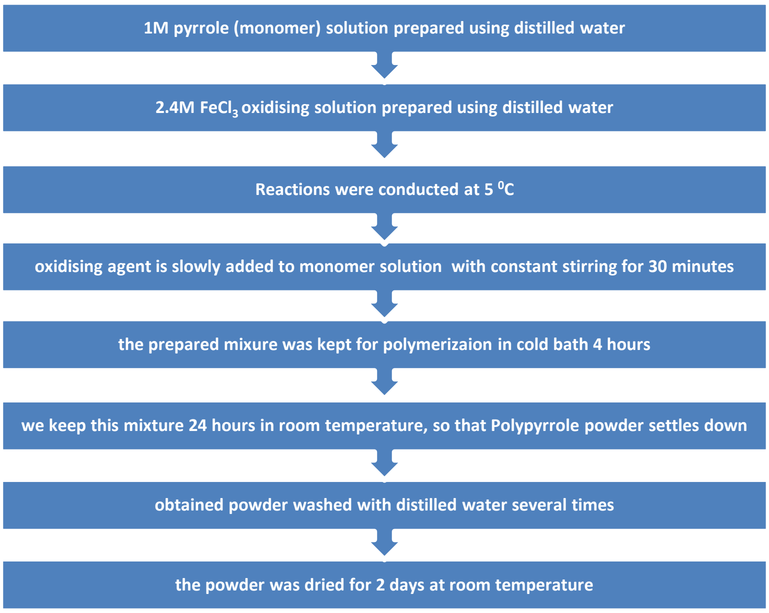

Figure 1: Schematic representation of synthesis of Polypyrrole.

Characterization Techniques

1 FTIR Spectroscopy

FTIR spectroscopy was used to identify functional groups and confirm polymer formation. Spectra were recorded in the mid-infrared region, where characteristic vibrational bands of polypyrrole are expected.

2 UV–Visible Spectroscopy

UV–Visible absorption spectroscopy was performed to study electronic transitions within the conjugated polymer chains. Absorbance was recorded as a function of wavelength.

3. Scanning Electron Microscopy (SEM)

SEM analysis was carried out to study the surface morphology and particle structure of the synthesized polypyrrole.

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4 Electrical Conductivity Measurement

Electrical properties were measured using the two-probe method. Pellets of known dimensions were prepared, and current–voltage (I–V) characteristics were recorded. Resistance was obtained from the slope of the I–V curve, and resistivity and conductivity were calculated.

Results and Discussion

1 FTIR Analysis

FTIR spectra of the synthesized polypyrrole showed characteristic absorption bands confirming successful polymerization. A peak near 784 cm^{-1} corresponds to C–N stretching vibrations. The band around 1300 cm^{-1} is attributed to C–H deformation. Strong peaks at 1536 cm^{-1} and 1451 cm^{-1} are associated with C=C stretching vibrations of the pyrrole ring. The presence of a band near ***1622 cm^{-1}*** corresponds to N–H vibrations. These peaks are consistent with reported values for polypyrrole, verifying the formation of the conjugated polymer structure. These peaks are consistent with previously reported FTIR spectra of chemically synthesized polypyrrole [3,10], confirming successful polymerization.

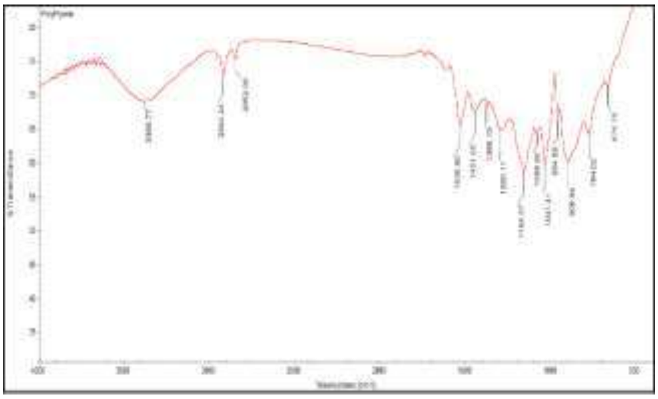

Figure 2: FTIR spectrum of synthesized polypyrrole showing characteristic vibrational bands**.**

2 UV–Visible Spectroscopy

The UV–Visible spectrum of polypyrrole exhibited absorption peaks around **230 nm** and **342 nm**, which are attributed to ***π–π**** electronic transitions within the conjugated backbone [11]]. These transitions confirm the presence of delocalized π-electrons, which are essential for electrical conductivity. The broad absorption profile also suggests the formation of polaron and bipolaron states due to oxidative doping. The presence of these transitions confirms the delocalized electronic structure necessary for charge transport. Similar absorption behavior has been reported for $FeCl_3$-doped polypyrrole [9].

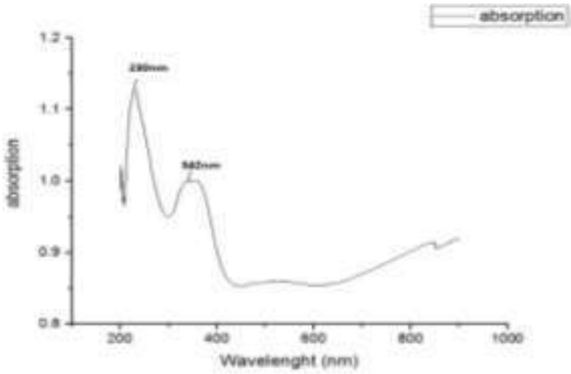

Figure.3 UV–Visible absorption spectrum of polypyrrole indicating π–π* electronic transitions.

3 SEM Morphological Analysis

SEM images revealed that the synthesized polypyrrole possesses a globular and granular morphology. The particles appear nearly spherical and closely packed, forming a continuous network. Such morphology supports effective charge transport by providing interparticle contact, which enhances electrical conductivity. The observed structure is typical of chemically synthesized polypyrrole and depends on the oxidant and reaction conditions.SEM micrographs showed globular and granular morphology, which is typical for chemically synthesized polypyrrole [8]. The morphology significantly influences charge transport because interparticle contact affects hopping conduction [12].

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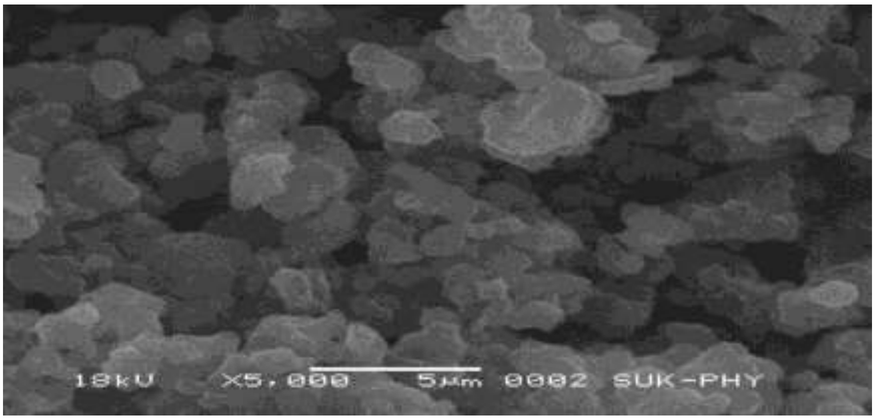

Figure 4: SEM micrograph of polypyrrole at 5 µm magnification showing globular morphology.

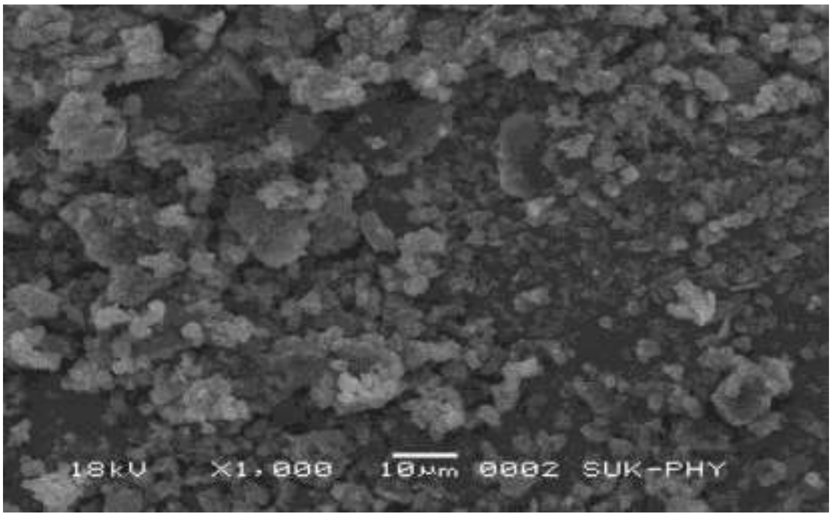

Figure 5: SEM micrograph of polypyrrole at 10 µm magnification showing closely packed granular structure.

4 Electrical Properties

The current–voltage measurements showed a nearly linear relationship, indicating ohmicbehavior. From the slope of the I–V graph, the resistance of the sample was calculated as 10 kΩ.

Using sample dimensions:

- Length = 0.5 cm
- Breadth = 0.4 cm
- Thickness = 0.8 mm

The resistivity was calculated to be approximately 704 Ω·m, and the electrical conductivity was found to be:

$\sigma=1.42\times10^{-3}$ S cm^{-1}

This conductivity value falls within the semiconducting range and confirms that oxidative doping using $FeCl_3$ effectively introduced charge carriers into the polymer chain.

Table 1: Measured voltage and corresponding current values for polypyrrole pellet used to determine electrical resistance.

Sl no	Voltage in volts (V)	Current in µA (I)
1	1.656	113.2
2	1.7	118
3	1.81	128.4
4	1.903	137.6
5	2.004	148.1
6	2.105	151.2
7	2.19	162.6
8	2.307	173.9

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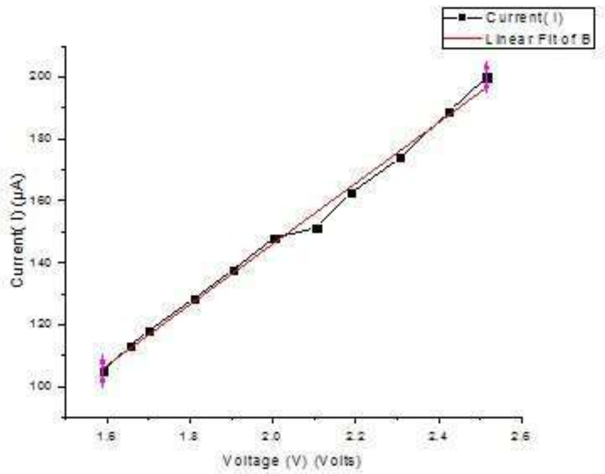

Equation	y = a + b*x		
Adj. R-Squar	0.9935		
		Value	Standard Err
B	Intercept	-50.0458	5.11589
B	Slope	98.05025	2.50624

Figure 6: Current–Voltage (I–V) characteristics of synthesized polypyrrole pellet.

Conduction Mechanism

Polypyrrole has a non-degenerate ground state, and charge transport occurs mainly through polarons and bipolarons formed during oxidation. The $FeCl_3$ oxidant removes electrons from the polymer backbone, creating positively charged defects. These charge carriers move along and between polymer chains via hopping mechanisms, leading to electrical conduction. Increased doping results in the formation of bipolarons, which further enhance conductivity by reducing the energy gap between the valence and conduction bands.

Conclusion

Polypyrrole was successfully synthesized using chemical oxidative polymerization with $FeCl_3$ as an oxidizing agent. FTIR analysis confirmed the formation of the characteristic polymer backbone, while UV–Visible spectroscopy verified the presence of conjugated π-electron systems. SEM studies revealed a globular morphology with closely packed particles, favorablefor charge transport. Electrical measurements demonstrated semiconducting behavior with a conductivity of 1.42×10^{-3} S cm^{-1}.

The results indicate that chemically synthesized polypyrrole possesses structural and electrical properties suitable for applications in sensors, corrosion-resistant coatings, energy storage systems, and environmental remediation. Further improvements in conductivity and mechanical properties may be achieved through composite formation or alternative doping strategies.

References

1. Skotheim, T. A., Reynolds, J. R. Handbook of Conducting Polymers, 3rd ed., CRC Press, 2007.
2. Diaz, A. F.; Kanazawa, K. K.; Gardini, G. P. "Electrochemical polymerization of pyrrole." Journal of the Chemical Society, Chemical Communications, 1979, 635–636.
3. Ansari, R. "Polypyrrole conducting electroactive polymers: synthesis and stability studies." E-Journal of Chemistry, 2006, 3(4), 186–201.
4. Shirakawa, H.; Louis, E. J.; MacDiarmid, A. G.; Chiang, C. K.; Heeger, A. J. "Synthesis of electrically conducting organic polymers." Journal of the Chemical Society, Chemical Communications, 1977, 578–580.
5. Heeger, A. J. "Semiconducting and metallic polymers: the fourth generation of polymeric materials." Journal of Physical Chemistry B, 2001, 105, 8475–8491.
6. MacDiarmid, A. G. "Synthetic metals: a novel role for organic polymers." Synthetic Metals, 2001, 125, 11–22.
7. Bredas, J. L.; Street, G. B. "Polarons, bipolarons, and solitons in conducting polymers." Accounts of Chemical Research, 1985, 18, 309–315.
8. Eisazadeh, H. "Studying the characteristics of polypyrrole and its composites." World Journal of Chemistry, 2007, 2(2), 67–74.

Journal of Research and Development
A Multidisciplinary International Level Referred and Double-Blind Peer Reviewed, Open Access
ISSN : 2230-9578 | Website: https://jrdrvb.org Volume-18, Issue-2(VI)| February- 2026

9. Chitte, H. K.; Bhat, N. V.; Walunj, V. E.; Shinde, G. N. "Electrical properties of polypyrrole prepared by chemical polymerization." Journal of Polymer Science, 2008.
10. Turcu, R.; Brie, M.; Leising, G. et al. "FTIR reflectance studies of electrochemically prepared polypyrrole." Synthetic Metals, 2001.
11. Bhat, N. V.; Gadre, A. P.; Bambole, V. A. "Structural, mechanical and electrical properties of polypyrrole." Journal of Applied Polymer Science, 2001.
12. Mott, N. F.; Davis, E. A. Electronic Processes in Non-Crystalline Materials, Oxford University Press, 1979.

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Original Article

The Study on Spectroscopic Infrared Characterization of Protocatechuic Acid

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Abstract

In this study, we investigated the basic ideas and real-world uses of infrared (IR) spectroscopy, concentrating on Protocatechuic acid. By identifying distinctive vibrational modes, infrared spectroscopy has proven to be an effective tool for molecular characterization, offering insight into the structural and functional components of organic compounds.

Introduction

IR spectroscopy is an essential analytical technique used in the identification and characterization of chemical compounds based on their interaction with infrared radiation. It is particularly valuable in organic and analytical chemistry due to its ability to provide insights into molecular structure and functional groups. The technique operates on the principle that molecules absorb specific frequencies of infrared light, causing them to undergo vibrational transitions. These absorptions are characteristic of the types of chemical bonds and atoms within a molecule, making IR spectroscopy a kind of molecular "fingerprinting."

IR spectroscopy is especially useful for identifying functional groups like hydroxyl (-OH), carbonyl (C=O), and amine ($-NH_2$), as these groups absorb IR radiation at characteristic frequencies. The resulting IR spectrum—a graph of absorbance or transmittance versus wavenumber—serves as a distinctive signature of the molecule

Molecular vibrations, such as stretching and bending of chemical bonds, occur when molecules absorb energy in the IR range. For a molecular vibration to be infrared-active, it must involve a change in the dipole moment of the molecule. When IR radiation is absorbed, these vibrations lead to a unique pattern of absorption bands in the spectrum, each corresponding to specific bond types and molecular structures.

IR spectroscopy offers a direct and reliable way to study the vibrational behaviour of molecules. Its ability to reveal structural details through characteristic absorption patterns makes it a foundational technique for understanding molecular identity and composition in chemical analysis.

Protocatechuic acid:

Protocatechuic acid or 3,4-dihydroxybenzoic acid is the major phenolic acid found in purple rice bran, grain brown rice and edible plants, and it has been shown to be a potential anti-cancer agent in humans' Different studies have been reported on PCA and its complexation and cluster formation with aqueous medium and other organic molecules. Motivations for these studies have sprung from PCA's diverse role as determined by its non-covalent interactions in therapeutic, polymorphism and drug dis-covery aspects Nangia group have studied polymorphism of the six isomeric forms of Dihydroxybenzoic acids with PCA being one of the isomers.

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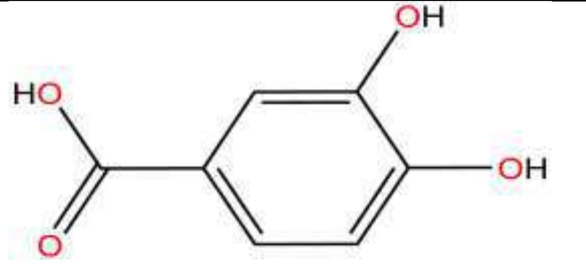

Figure.1 Molecular structure of

Protocatechuic acid (PCA) was selected for this project due to its remarkable spectrum of biological activities, including potent antioxidant, anti-inflammatory, antimicrobial, and anti-cancer effects. These diverse properties align well with the objectives of our research. Structurally, PCA contains both phenolic hydroxyl groups and a carboxylic acid moiety—functional groups that significantly contribute to its chemical reactivity and biological efficacy. Moreover, these groups exhibit characteristic signals in spectroscopic techniques such as IR and UV-Visible spectroscopy, facilitating straightforward identification and analysis. Collectively, these attributes made PCA a highly suitable compound for our study.

In this work we studied IR spectroscopy of Protocatechuic acid using experimental IR spectroscopy. It demonstrates excellent agreement between theoretical and experimental vibrational modes.

In the analysis of molecular vibrations, a particularly important class of solutions arises when all atoms oscillate harmonically with a common frequency and phase. The displacement of the i-th atom in the k-th normal mode is given by

$$A_{ik}=K_k h_k$$

where K_k is a normalization constant and h_k is the eigenvector component associated with the k^{th} mode. The frequency of oscillation is

$$\vartheta_k = \frac{\lambda_k}{2\pi}$$

Where ϑ_k is Frequency (Hz) of the k-th normal mode, $\lambda_k/2\pi$ is Angular frequency (radians/second).

Notably, for a given normal mode, each atom undergoes simple harmonic motion at this same frequency and with the same phase, though the amplitude A_{ik} may vary between atoms. Consequently, all atoms pass through their equilibrium positions and reach their maximum displacements simultaneously. A vibrational motion with these characteristics is defined as a normal mode, and its associated frequency is termed a normal (or fundamental) frequency of the molecule. These normal modes form the natural basis for describing the vibrational behaviour of polyatomic systems and are fundamental to molecular spectroscopy.

Experimental Techniques:

A sample is prepared then inserted in the radiation path and the process repeated. The ratio of sample and reference spectral data is then computed to give the transmittance at various frequencies. From this ratio the absorbance is calculated as a function of wavenumber. Ordinarily, modern IR sources and detectors are sufficiently stable so that reference spectra need to be obtained only occasionally.

A double-beam spectrometer is illustrated the above figure The mirrors directing the interferometer beam through the sample and reference cells are oscillated rapidly compared to the movement of the interferometer mirror so that sample and reference information can be obtained at each mirror position. The double-beam design compensates for source and detector drifts. Performance Characteristics of Commercial Instruments

Double-beam FTIR spectrometer. The beam emerging from the interferometer strikes mirror m1, which in one position directs the beam through the reference cell and in the other position directs it through the sample cell. mirror m2, which is synchronized to m1, alternately directs the reference beam and the sample beam to the transducer.

Nicolet FTIR Spectrometer are the highest performance FTIR systems available. The high-performance spectrometer has the power to handle both research and routine analysis experiments. Nicolet 6700 FTIR laboratory Spectrometer contains extensive internal controls, controlling filters, polarizers and mirror for specific applications through the OMNIC software.

1 Sample preparation:

Method of preparing pellet:

- One of most popular techniques has hardly relied Samples has been KBr pelleting.
- In using this technique, a milligram or less of the finely powdered sample is mixed with about 100 mg of KBr powder. Mixing can be carried with a mortar and pestle in a small ball mill.
- Then the mixture is then pressed by a spectral special die at 10,000 to 15,000 pounds per square inch to yield a transparent disc.

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- The KBr disc is then held in the instrument beam for spectroscopic examination.
- With many compounds, KBr pelleting produces excellent spectra that appears in many spectral libraries. Being ionic, KBr transmits throughout most of the IR region with lower cut off of about 400 cm^{-1}

Figure. 1 Represents Protocatechuic acid pallet form.

2. Smart purge system:

Water and A robust purge system with nitrogen gas helps to minimize the interference from carbon dioxide, particularly for the important sensitive measurements. The unique Smart Purge system available for the Nicolet FT-IR automatically detects when you have opened the spectrometer door. Smart Purge then automatically increases the flow of purge gas in your spectrometer to blast the sample compartment area free from unpurged lab air. Smart Purge automatically turns itself down when the spectrometer is ready to collect data, and provides the fastest possible purge recovery time in between successive samples to ensure that you are collecting data as quickly and efficiently as possible.

3 Vectra Interferometer:

Vectra interferometer is a type of Michelson interferometer but with advancements like a dynamic alignment system and air bearing interferometer with added advantage of not requiring an external air supply. The standard resolution of the Nicolet 6700 spectrometer is 0.009 cm^{-1}.

The Vectra interferometer often feature an air bearing design which minimizes friction and allows for precise and stable mirror movement. Dynamic alignment includes that system continuously adjust the interferometer to compensate for and maintain optical performance.

4 Software:

OMNIC software for Nicolet FT-IRspectrometers provides a powerful Windows compatible interface for complete data collection and processing live data displays, active spectrometer diagnostics, and spectral quality checking assure the best possible data. Extensive data processing analysis and reporting tools allow you to make the most of your results and it has the most extensive on-line help system currently available, which includes FT-IR theory sample handling. OMNIC software is available in five languages (English, Spanish, French, German, and Japanese).

5 Molecular description:

Physical Properties of Protocatechuic Acid:

- Appearance: It is a crystalline solid, usually off-white or light beige in color.
- State: Solid at room temperature.
- Melting Point: It melts at approximately 199–203 °C.
- Boiling Point: It decomposes before reaching its boiling points
- Density: It has a density of about 1.53 g/cm^3.
- Solubility in Water: Moderately soluble, with better solubility in hot water.
- Solubility in Organic Solvents: Soluble in ethanol, slightly soluble in ether.
- Odor: Generally, Odor less.
- Thermal Stability: Sensitive to heat; decomposes at high temperatures.
- Molecular formula: $C_7 H_6 O_4$.

On the right side of the image, there is a black-framed image displaying a 3D ball-and-stick model of a molecule. The model shows a six-membered ring (likely a benzene ring) with blue spheres representing carbon atoms. Attached to the ring are red spheres (representing oxygen atoms) and smaller white spheres (representing hydrogen atoms), consistent with the structure of protocatechuic acid.

Chemical properties of Protocatechuic acid:

- Acidic Nature: It is a weak acid due to the presence of a carboxylic acid group and two phenolic hydroxyl groups.
- Diprotic Character: Can donate two protons: one from the -COOH group and one from the phenolic -OH.
- Antioxidant Activity: Acts as an antioxidant by donating hydrogen atoms from its hydroxyl groups to neutralize free radicals.
- Oxidation Reaction: Can be oxidized to form quinone-like compounds.
- Chelation Ability: Binds to metal ions like Fe^{+3} and Cu^{+2}, forming stable chelates.
- Reactivity with Bases: Forms water-soluble salts (e.g., sodium protocatechuate) when reacted with bases.
- Esterification: The -OH and -COOH groups can form esters when reacted with alcohols or acid chlorides

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- Decarboxylation: Can lose the carboxylic acid group as CO_2 under heat, forming catechol.
- Electrophilic Substitution: The aromatic ring undergoes substitution reactions due to activation by -OH groups.
- Biotransformation: In the body, it undergoes methylation, glucuronidation, and sulfation during metabolism.

Results and Discussion:

Spectra structure correlation:

Spectra-structure correlation refers to the systematic relationship between a molecule's spectroscopic features and its chemical structure. It is the basis for identifying and characterizing molecular frameworks using techniques such as infrared (IR)**,** nuclear magnetic resonance (NMR)**,** mass spectrometry (MS)**,** and ultraviolet-visible (UV-Vis) spectroscopy**.** Each functional group or bond type within a molecule absorbs or emits electromagnetic radiation at characteristic frequencies or energies, generating unique signals or bands in a spectrum. By interpreting these spectral patterns, specific **structural elements** such as double bonds, carbonyl groups, aromatic rings, or heteroatoms can be identified.

Table 1. Theoretical spectra structure correlation.

Standard wavenumbers (cm^{-1})	**Assignments**
1600-1000	C=C stretching
>1200	CH-in plane bending
<1200	CH-in plane bending
1305.7098	C-0 bond stretching
1600-1500	C=C stretching
1600-1500	C=C stretching
1420-1400	O-H in plane bending
710-665	C-C out of plane bending
870	Hydrogen Wag
750	CH-Wag
940	CH-wag
820	CH-Wag
1000-700	CH- Out of Plane bending
1650-1540	C-H Bending
1260 -1180	C-O stretching
3250-3200	OH, stretching in ring
1260-1180	C-O stretching
650	C—OH Out of Plane deformation
1300-1200	CH-in plane bending
1330	C-O stretching, CH in plane bending
1390-1330	CH Bending
1650-1540	C=0 stretching
608	C-C out of plane bending
476-428	out of plane aromatic deformation

Table 2.

The Observed Spectra correlation

Observed wave number(cm^{-1})	**Assignments**
3273,3580,3677	OH, stretching in ring
1219,1305	CH-in plane bending
1187	CH-in plane bending
1311	C-0 bond stretching
1530,1451,1423,1608	C=C stretching
1423,1219	I in plane bending in hydroxylic & in carboxylic acid
683	OH, out of Plane Bending
872	Hydrogen Wag
766	CH-Wag
947	CH-wag
825	CH-Wag
794	CH- Out of Plane bending
1368	C-H Bending

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1250	C-O stretching
3273,3011,3069	OH, stretching in Carboxylic acid
1250	C-O stretching
636	C—OH Out of Plane deformation
1305,1219,1250	CO stretching in carboxylic acid
1368	CH Bending
1660	C=0 stretching
613	C-C out of plane bending
451	out of plane aromatic deformation

1 Experimental Observation of IR spectrum of Protocathuic acid:

Protocatechuic acid, also known as 3,4 dihydroxybenzoic acid, is an organic compound, that belongs to the class of hydroxybenzoic acid. It consists of three functional groups namely: two hydroxyl groups (-OH): one at meta position (3rd position) and one at para position (4thposition) & carboxylic acid group (-COOH) at the 1st position.

The molecular formula of Protocatechuic acid is $C_7H_6O_4$. There are **17** total number of atoms present. Since the number of vibrational normal modes for a non-linear molecule is 3N-6, the total number of normal modes of vibration for Protocatechuic acid is **45**. The experimental IR spectrum of Protocatechuic acid is as shown in below given Figure

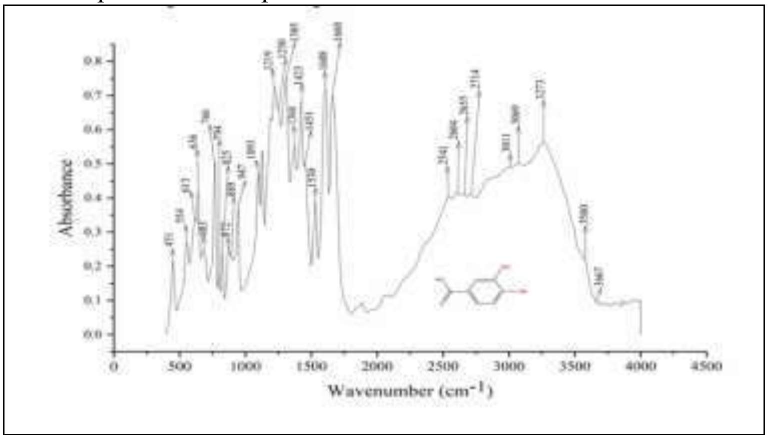

Figure 3.1 represents the experimental IR spectrum of Protocatechuic acid

Brief discussion of the normal modes of vibration of protocatechuic acid molecule is outlined below:

A) Benzene Ring:

The benzene ring in Protocatechuic acid forms the aromatic backbone. It has six Carbon atoms in a conjugated cyclic system, with 3 Hydrogen atoms attached to the ring in addition to the 3 functional groups attached. The vibrations associated with this part include:

- C-H bond (aromatic): The C-H stretching in this molecule is likely to occur in the region of wavenumbers ranging between 3100-3000 cm^{-1}. We have observed the C-H stretching at 3011 & 3009 cm^{-1} wavenumbers.
- C-H in plane bending: The C-H in plane bending occurs in the region between 1300-1000 cm^{-1} & we have experimentally observed this at wavenumbers 1305 & 1219 cm^{-1}.
- C-H out of plane bending: The C-H out of plane bending occurs in the region between 900-675 cm^{-1} and we have observed the same at 794 cm^{-1} wave number experimentally.

B) Hydroxyl group:

- OH, stretching vibration: The OH stretching vibrations occurring in the phenolic OH groups are observed in the broad-spectrum region of 3700- 3100 cm^{-1}. We have_experimentally observed the same at wavenumbers 3273, 3580 and 3677 cm^{-1}.
- O-H in plane bending: The O-H in plane bending occurs in the region of 1400-1200 cm^{-1}. We have observed the same at 1219 & 1423 cm^{-1}.
- O-H out of plane bending: The O-H out of plane bending occurs in the region 650-1000 cm^{-1} and we have observed the same at 683 cm^{-1}.

C) The carboxylic acid group:

- O-H Stretching (COOH): This is usually observed in the region 3300-2500 cm^{-1}. We have observed the same at 3011, 3069, 3273 cm^{-1}.
- C=O Stretching: This is usually observed in the region 1760-1690 cm^{-1}. We have observed the same at 1660 cm^{-1}.
- C-O Stretching: This is usually observed in the region 1320-1210 cm^{-1}. We have observed the same at 1305, 1219, 1250 cm^{-1}.
- O-H In-plane Bending: This is usually observed in the region 1440-1395 cm^{-1}. We have observed the same at 1423, 1451 cm^{-1}.

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Conclusion:

In this work, we explored the fundamental principles and practical applications of infrared (IR) spectroscopy, with a focused analysis on protocatechuic acid. IR spectroscopy proved to be a powerful tool for molecular characterization, providing insight into the structural and functional components of organic compounds through the identification of characteristic vibrational modes.

Protocatechuic acid, a naturally occurring hydroxybenzoic acid, was selected for spectral analysis due to its well-defined functional groups—namely, two phenolic hydroxyl groups and a carboxylic acid group. Through detailed examination of its IR spectrum, we were able to correlate specific absorption bands to stretching and bending vibrations associated with these groups. Notable features included broad O–H stretching vibrations in the 3273–3677 cm^{-1} range, C=O stretching around 1530 cm^{-1}, and multiple C–H bending and wagging modes consistent with the aromatic backbone. The spectra-structure correlation demonstrated a high degree of agreement between theoretical expectations and experimentally observed wavenumbers.

Furthermore, by applying group frequency analysis and vibrational mode assignments, we determined that protocatechuic acid exhibits 45 normal modes of vibration, in line with theoretical predictions for a 17-atom nonlinear molecule.

Overall, this study confirms the effectiveness of IR spectroscopy as a non-destructive and reliable analytical technique for functional group identification and structural elucidation. It reinforces the importance of vibrational spectroscopy in organic chemistry, pharmaceuticals, and biochemical research, particularly when used in combination with molecular knowledge and theoretical predictions.

References:

1. Introduction to spectroscopy by Pavia, Lampnan, Kriz,
2. Fundamentals of physics by Hallidsy, Resnick and Walker Banwell & McCash Silverstein,
3. Fundamentals Of molecular spectroscopy by C.N Banwel
4. Introduction to Infrared Spectroscopy by skoog, https||mmrc, Caltech.edu
5. S. Kakkar, S. Bais, A review on protocatechuic acid and its pharmacological potential, ISRN Pharmacol. https://doi.org/10.1155/2014/952943.
6. T.A. Pujari, Cocrystals of nutraceuticals: Protocatechuic acid and quercetin 101,2009. http://scholarcommons.usf.edu/etd/2156/.
7. Colthup Norman Introduction to IR and Raman Spectroscopy / Norman B

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Original Article

Determination of Mercury Concentration in Soil Samples from the Sandur Mining Region Using Nuclear Technique

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Abstract

Mercury (Hg) is a persistent and toxic environmental contaminant that accumulates in soils due to both natural processes and anthropogenic activities. Accurate quantification of trace mercury in soils is critical for environmental monitoring and risk assessment. The present study investigates trace mercury concentrations in soil samples collected from five locations within the Sandur mining region, Karnataka, India. Soil samples were collected from Swamymallai Block, Ramanmalai, Dowlatpur, Kallahalli, and Jambunathalli. Samples were air-dried, homogenised, and analysed using the sample dilution method coupled with Total Reflection X-Ray Fluorescence (TXRF). Mercury concentrations ranged from 0.15 to 0.50 mg/kg, with the highest concentration observed at Jambunathalli. The results indicate moderate mercury enrichment in areas influenced by mining activities. Continuous monitoring is recommended to evaluate long-term environmental impacts in the Sandur mining belt.

Keywords: *Trace Mercury; Soil contamination; TXRF; Environmental monitoring; Heavy metals*

Introduction

Mercury (Hg) is a globally recognised toxic trace metal due to its persistence, long-range atmospheric transport, and ability to bioaccumulate in ecosystems. It exists in multiple chemical forms, including elemental mercury (Hg^0), inorganic mercury (Hg^{2+}), and organic species such as methylmercury (MeHg), each differing in environmental behaviour and toxicity [1]. Among these forms, methylmercury is particularly hazardous because of its high bioavailability and tendency to bio-magnify in food chains, posing serious neurological and developmental risks to humans and wildlife [2]. Once released into the environment, mercury participates in complex biogeochemical cycling involving atmospheric deposition, soil adsorption, leaching, and microbial transformation [3].

Soils act as major sinks for atmospheric mercury deposition and play a critical role in regulating its mobility and long-term storage. However, soils can also serve as secondary sources of mercury through volatilisation and surface runoff under changing environmental conditions [4]. Natural background concentrations of mercury in uncontaminated soils typically range from 0.01 to 0.10 mg/kg, depending on parent material and regional geochemistry [5]. Elevated concentrations are generally associated with anthropogenic activities such as mining, fossil fuel combustion, waste incineration, and industrial emissions. Mining activities are considered significant contributors to heavy metal contamination in terrestrial ecosystems. During excavation, drilling, blasting, and ore processing, trace elements present in mineralised rock formations may be mobilised and dispersed into surrounding soils and water bodies [5].

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Even when mercury is not the primary commodity mined, associated trace quantities can be released through mechanical disturbance and weathering of ore and overburden materials. Mine tailings, waste dumps, and airborne particulate emissions further enhance the redistribution of trace metals into adjacent environments [6].

The Sandur mining region in Karnataka, India, is well known for extensive iron ore mining operations. Open-cast mining in this area has led to substantial landscape alteration, deforestation, and increased generation of mine waste. Continuous extraction and transportation activities may contribute to the dispersion of metal-bearing dust particles that eventually settle onto nearby soils. Over time, such processes can result in localised enrichment of trace metals, including mercury, thereby affecting soil quality and ecological health. Monitoring mercury concentrations in mining-impacted soils is therefore essential for environmental risk assessment and sustainable land management.

Accurate determination of trace mercury levels in soil requires sensitive analytical techniques capable of detecting low concentrations with high precision. Conventional methods such as Cold Vapour Atomic Absorption Spectroscopy (CVAAS) and Inductively Coupled Plasma Mass Spectrometry (ICP-MS) are widely used for mercury analysis due to their sensitivity and reliability [7]. However, Total Reflection X-Ray Fluorescence (TXRF) has emerged as a rapid and cost-effective alternative for multi-element trace analysis [8]. TXRF offers advantages including minimal sample preparation, low reagent consumption, small sample volume requirements, and excellent detection limits [9]. When combined with appropriate digestion and internal standardisation, TXRF provides accurate quantification of trace mercury in environmental samples.

In this context, the present study aims to determine trace mercury concentrations in soil samples collected from selected locations within the Sandur mining region using the sample dilution method coupled with TXRF analysis. The study seeks to evaluate spatial variability in mercury distribution and assess the potential influence of mining activities on soil contamination levels.

Materials and Methods

1. Study Area

The present study was conducted in the Sandur mining region, located in Ballari (Bellary) district, Karnataka, India. The area is characterized by extensive open-cast iron ore mining, overburden dumping, and ore transportation activities. The terrain consists predominantly of lateritic soils and mineral-rich formations. Continuous mining operations and associated anthropogenic disturbances make this region suitable for assessing trace metal contamination in soils.

2. Chemicals and Reagents

All reagents used in this study were of analytical grade. Nitric acid (HNO_3, 65%) and hydrochloric acid (HCl, 37%) were used for sample carrier washing. Triton X-100 and Deionised water (resistivity ≥ 18 MΩ·cm) were used for dilution and preparation of solutions. Selenium (Se) standard solution was used as an internal standard for TXRF quantification. All glassware and sample containers were soaked in 10% nitric acid for 24 hours and rinsed thoroughly with deionised water before use to avoid contamination.

3 Sample Collection

Five surface soil samples were collected from different locations within the Sandur mining region:

- Swamymallai Block (S1)
- Ramanmalai (S2)
- Dowlatpur (S3)
- Kallahalli (S4)
- Jambunathalli (S5)

Surface soils were collected from a depth of 0–15 cm using a stainless-steel auger to minimise metal contamination. At each location, subsamples were collected from multiple points and composited to obtain representative samples. Approximately 0.5 kg of soil was collected per site and stored in clean polyethene bags. Samples were labelled properly and transported to the laboratory for further analysis.

4 Sample Preparation for TXRF Analysis (Suspension Method)

Trace mercury analysis was performed using the suspension method suitable for Total Reflection X-Ray Fluorescence (TXRF) analysis. This method minimises extensive acid digestion and allows rapid preparation with reduced reagent consumption.

Approximately 50 mg of finely powdered soil sample (previously air-dried, sieved through 2 mm mesh, and homogenised using an agate mortar) was accurately weighed and transferred into a clean polypropylene microcentrifuge tube. The sample was dispersed in 2.5 mL of Triton X-100 solution (non-ionic surfactant, typically 1% v/v prepared with deionised water) to obtain a stable and homogeneous suspension. Triton X-100 facilitates uniform particle dispersion and improves film formation on the reflector surface.

To each suspension, 10 µL of selenium (Se) standard solution (1000 mg/L) was added as an internal standard. Selenium was selected due to its absence in significant concentrations in the soil matrix and its suitable fluorescence response under TXRF conditions. The internal standard corrects for instrumental variations, matrix effects, and sample deposition inconsistencies.

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The mixture was vortexed thoroughly for several minutes to ensure complete homogenization and uniform distribution of both soil particles and internal standard.

A 10 µL aliquot of the well-mixed suspension was carefully pipetted onto a pre-cleaned quartz sample carrier (reflector). Prior to use, quartz carriers were cleaned with dilute nitric acid, rinsed with deionized water, and dried to prevent contamination.

The deposited aliquots were dried at 70°C in a drying oven to form a thin, uniform residue layer. Controlled drying temperature ensured gradual solvent evaporation, preventing splashing or uneven distribution of particles, which could affect analytical accuracy.

Once dried, the reflectors were transferred to the TXRF sample holder for analysis.

Results and Discussion

The mercury concentrations in the analysed soil samples are presented below:

Location	Sample ID	Hg (mg/kg)
Swamymallai Block	S1	0.15
Ramanmalai	S2	0.34
Dowlatpur	S3	0.16
Kallahalli	S4	0.17
Jambunathalli	S5	0.50

Mercury concentrations ranged from 0.15 to 0.50 mg/kg, with an average value of 0.264 mg/kg.

The highest concentration was observed at Jambunathalli (0.50 mg/kg), followed by Ramanmalai (0.34 mg/kg). These locations may be closer to active mining operations or waste disposal sites, contributing to localized enrichment.

Lower concentrations were observed at Swamymallai Block, Dowlatpur, and Kallahalli (0.15–0.17 mg/kg), suggesting comparatively lower mining influence.

Typical background mercury levels in natural soils range between 0.01 and 0.10 mg/kg. The concentrations observed in this study exceed background levels, indicating anthropogenic contribution, likely due to mining activities. However, the detected concentrations remain below many international soil quality guideline limits (approximately 1–2 mg/kg). Thus, the contamination level may be categorised as moderate but not critical. Long-term accumulation and possible methylation of mercury under suitable environmental conditions may pose ecological risks. Continuous environmental monitoring is therefore recommended.

Conclusion

The present study successfully determined trace mercury concentrations in soil samples from the Sandur mining region using the sample dilution method coupled with TXRF analysis. Mercury levels ranged from 0.15 to 0.50 mg/kg, with higher concentrations observed near mining-influenced areas. The TXRF technique proved to be an effective, rapid, and sensitive method for trace mercury analysis in soil samples. Current concentrations are above major regulatory thresholds; the observed enrichment suggests the influence of mining activities. Periodic monitoring is recommended to prevent potential long-term environmental impacts.

References:

1. Z. Rahman, V.P. Singh, The relative impact of toxic heavy metals (THMs)(arsenic (As), cadmium (Cd), chromium (Cr)(VI), mercury (Hg), and lead (Pb)) on the total environment: an overview, Environ. Monit. Assess. 191 (2019) 1–21.
2. J.C. Bare, Risk assessment and life-cycle impact assessment (LCIA) for human health cancerous and noncancerous emissions: integrated and complementary with consistency within the USEPA, Hum. Ecol. Risk Assess. 12 (2006) 493–509.
3. J. Wang, J. Yang, T. Chen, Source appointment of potentially toxic elements (PTEs) at an abandoned realgar mine: Combination of multivariate statistical analysis and three common receptor models, Chemosphere. 307 (2022) 135923. https://doi.org/10.1016/j.chemosphere.2022.135923.
4. J. Kumpiene, A. Lagerkvist, C. Maurice, Stabilization of As, Cr, Cu, Pb and Zn in soil using amendments – A review, Waste Manag. 28 (2008) 215–225. https://doi.org/10.1016/j.wasman.2006.12.012.
5. D.C. Adriano, Trace elements in terrestrial environments: biogeochemistry, bioavailability, and risks of metals, Springer, 2001.
6. M. Varol, M.R. Sünbül, H. Aytop, C.H. Yılmaz, Environmental, ecological and health risks of trace elements, and their sources in soils of Harran Plain, Turkey, Chemosphere. 245 (2020) 125592. https://doi.org/10.1016/j.chemosphere.2019.125592.
7. M. Patriarca, N. Barlow, A. Cross, S. Hill, A. Robson, A. Taylor, J. Tyson, Atomic spectrometry update: review of advances in the analysis of clinical and biological materials, foods and beverages, J. Anal. At. Spectrom. 37 (2022) 410–473.

8. E. Marguí, D. Eichert, J. Jablan, F. Bilo, L.E. Depero, A. Pejović-Milić, A. Gross, H. Stosnach, A. Kubala-Kukuś, D. Banaś, L. Borgese, An overview of the applications of total reflection X-ray fluorescence spectrometry in food, cosmetics, and pharmaceutical research, J. Anal. At. Spectrom. 39 (2024) 1700–1719. https://doi.org/10.1039/D4JA00096J.
9. Z. Polgári, N. Szoboszlai, M. Óvári, G. Záray, Possibilities and limitations of the total reflection X-ray fluorescence spectrometry for the determination of low Z elements in biological samples, Microchem. J. 99 (2011) 339–343. https://doi.org/10.1016/j.microc.2011.06.002.

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Original Article

Electronic Voting Machine Authentication through Enhancing Biometric Information

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Abstract

This paper describes an online electoral voting system. The voting system is managed in a easier way as all the users should login by Aadhar card number and name and click on his/her favourable candidates to cast the vote. This features a larger security in the sense that voter's high security Aadhar card number is confirmed before the vote is accepted in the main database of ECI (Election Commission of India). The extra feature of the model is that the voter will ensure if his/her vote has gone to correct candidate/party. The votes are going to be done automatically, therefore saving an enormous time and facultative ECI to announce the result at intervals a very short period.

Key words: *Election Commision of India, Sensor, electrical Voting System*

Introduction

This paper examines policy regarding the electronic approaches and developments towards electronic data storage and transmission. Finger print devices for voting machines and different existing identity documents are mentioned and enforced during this project.

The Electronic voting machines (EVMs) have revolutionized the electoral process by providing a secure and efficient mean of authenticity, which was a critical matter of concern. This paper explores the user of biometric information as a means of enhancing electronic voting machine authentication thereby mitigating potential security risks and ensuring the accuracy of the election results. The study examines various biometric modalities, such as finger print etc in electronic voting machine authentication. Additionally, it discusses the challenges and ethical considerations associated with implementing biometric authentication in the context of electronic voting machine.

In the recent years, electronic voting machines have gained popularity due to their efficiency and convenience in the electoral process. However, concerns regarding the security and authentication of these machines have also emerged. To address these concerns, there is growing need to enhance the authentication process of electronic voting machines through the use of biometric information. The present voting system is inefficient as the voters registration process is slow, the manual collection of results takes time and gives room for result manipulation, also the inaccessible nature of election venues which includes the long distance to be collected by voters to their register location increases voters apathy towards the election process, and final the issues of a ballot snatching and damage also the other election violence and issues associated with the traditional voting all defiles the purpose of voting in election process.

Materials and Methods:

The methodology of choice is rapid application development (RAD); this is because the objectives of RAD include high speed, high quality and lowered cost. RAD emphasizes the use of special techniques and computer tools to speed up analysis, design and implementation phases.

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Techniques, include computer assisted software engineering (CASE) tools, joint application design (GAD) and fourth generation programming languages. All of which are inline and essential to the proposed system. The RAD methodology goes through the following phases:

Phase 1:

Requirements planning: Refers to a review of the voters' areas immediately associated with the propose system.

Areas associated with the proposed system includes:

- Mode of user voting
- Mode of voter authentication
- Mode of data collection and verification
- Mode of data communication

Phase 2:

User Design: This stage would use various software modelling tools to illustrate the systems data and process and to build a visual representation of critical system components. Also, the programming tools chosen to implement the proposed system were stated. A key milestone of this proposed system is to make it a much user friendly and easy to use.

Results and Discussion:

Electronic voting machine (EVM) have revolutionized the electoral process by providing a secure and efficient means of casting votes. Traditional EVMs have relied on physical buttons or touch screen for voter input. However, the integration of biometric technology, specifically fingerprint recognition, has further enhanced the security and integrity of the voting process. Fingerprint based electronic voting machine, let the voters to caste their votes using their fingerprint as form of identification.

1 Working of fingerprint based electronic voting machine include following steps.

- Enrollment
- Delete
- Matching
- Verification
- Voting
- Result

Enrollment: Prior to the election the voters need to register their fingerprint in EVM (electronic voting machine) System. In this process the fingerprint of each voter is captured and associated them with their personal information which includes, name, address and unique identity of every individual like aadhar and voter ID

.

- **Initialization:** The EVM is initialized and prepared for the enrolment process
- **Registration:** The voter approaches the EVM and provides their identification details such as name, address, voter ID to the election official.
- **Fingerprint scanning:** The voter's fingerprint is scanned using fingerprint sensor integrated into the EVM. The sensor captures the unique patterns and characteristic of the voter's fingerprint.
- **Fingerprint template:** The captured fingerprint data is processed and converted into a unique fingerprint template. This template is a mathematical representation of the fingerprint, which can be used for comparison and identification purposes.
- **Linking:** Linking the fingerprint template with voter details: The created fingerprint template is linked to the voter's registration details.

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Delete: After the completion of Electoral process, the stored data in EVM system need to be deleted so that the EVM system is ready to use for different electoral process. The delete port can also be used delete to the invalid biometric data

.

Matching in an EVM: Matching in an Electronic Voting Machine with a fingerprint sensor typically involves the following steps

- **Voting:** When a voter approaches the EVM to cast their vote, they place their finger on the fingerprint sensor. The sensor captures their fingerprint and converts it into a digital template.

- **Template Comparison:** The digital template obtained from the voter's fingerprint is compared with the stored templates in the database. This comparison is usually done using algorithms that analyze the unique patterns and features of the fingerprint

Verification: Verification in an Electronic Voting Machine (EVM) with a fingerprint sensor involves using a person's fingerprint to authenticate their identity before allowing them to cast their vote. This integration would help prevent fraudulent voting practices such as impersonation or multiple voting by the same person. The fingerprint sensor would ensure that only eligible voters can participation the election, as each person's fingerprint is unique and cannot be easily replicated.

Additionally, the fingerprint sensor would provide a more efficient and streamlined voting process. Voters would no longer need to present identification documents or go through manual verification processes, as their fingerprint would serve as their identification. This would save time and reduce the fraud.

- **Fingerprint Matching:** The captured fingerprint is then compared with the stored fingerprints in the database to find a match. If a fingerprint is matched it allows the voter to cast their vote. If not, it denies the voter to cast their vote and display's 'fingerprint doesn't match'. If a same person tries to cast the vote for multiple times it rejects by displaying 'ALREADY VOTED'.

Voting: Voting in an Electronic Voting Machine (EVM) with a fingerprint sensor involves the use of biometric authentication to verify the identity of the voter. The authenticated voters are allowed to cast their vote by pressing the ballot button corresponding to the candidate of their choice.

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Result: Once all the voting process is completed the result of complete electoral process is calculated by the EVM itself and result is displayed.

Circuit Diagram and Working Model

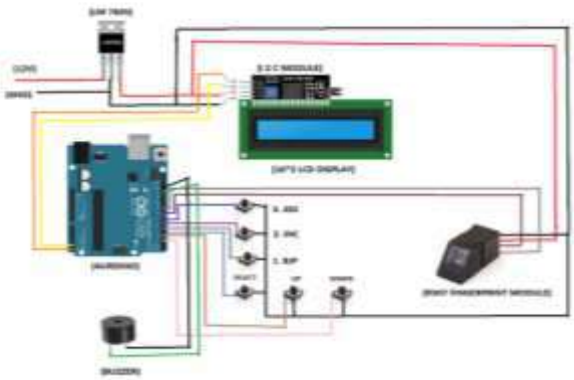

Figure. 1 Represents the circuit diagram of Electronic Voting Machine

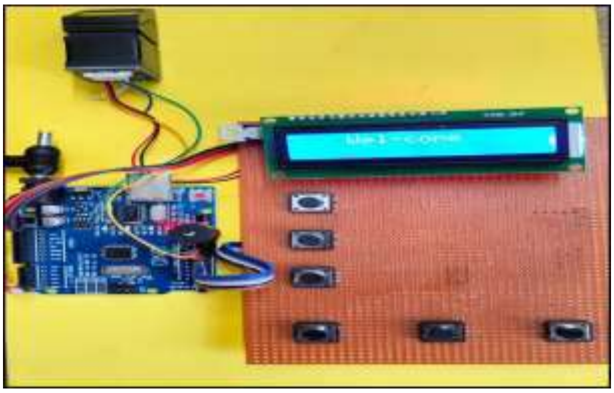

Figure. 2 Represents the working Model of Electronic Voting Machine

Program Code

```
#include<LiquidCrystal_I2C.h>
int result_flag = 0;
//char party_1[10];
//char number_1[5];
bool OneTimeExe = 0;

//int relay = 7;
#define UP  2
#define DN  3
```

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```
#define SL  4
#define BJP  5
#define CONG  6
#define JDS  7
int BJP_count = 0, CONG_count = 0, JDS_count = 0;

LiquidCrystal_I2C lcd(0X26 , 16 , 2);
int f1 = 0, f2 = 0, f3 = 0, f4 = 0,f5  =0;

unsigned char recv_buf[16] = {'\0'}, buff[17];
unsigned char i, page_id1, page_id2;
char OPTIONSsELaRRY[3][17] = {" < ENROLLMENT > ",
                              " < DELETE ID  > ",
                              " <  MATCHING  > "
                             };

void result_fun(void);
unsigned char reactivate_sensor(void);
void send_image_take_code(void);
unsigned char uart_receive_char (void);
unsigned char recv_ack(unsigned char buf_size);
void create_char_file1(void);
void create_char_file2(void);
unsigned char entry_finger(void);
void create_template(void);
void search_template(void);
unsigned char store_finger(void);
void read_template_number(void);
void store_template(void);
void deletfuncall(void);
void matchingfunction(void);
void putfingeronredlight(void);
void putfingeronredlight(void);
void empty_flash(void);


void result_fun(void)
{
  result_flag = 1;
}

unsigned char reactivate_sensor(void)
{
  do
  {
    send_image_take_code();
    recv_ack(12);
  } while (recv_buf[9] != 0x00);

  if (recv_buf[9] == 0x00)
  {
    create_char_file1();
    recv_ack(12);
    do
    {
      send_image_take_code();

    } while (recv_ack(12));
    create_char_file2();
```

```
    recv_ack(12);
    return (0);
  }
  return (1);
}

void send_image_take_code(void)
{
  Serial.write(0xEF);
  Serial.write(0x01);
  Serial.write(0xFF);
  Serial.write(0xFF);
  Serial.write(0x03);
  Serial.write(0x01);
  Serial.write(0x00);
  Serial.write(0x05);
}

unsigned char uart_receive_char (void)//UInt8
{
  unsigned char received_data = 0;
  while (Serial.available() == 0);
  received_data = Serial.read();
  return (received_data);
}


unsigned char recv_ack(unsigned char buf_size)
{
  unsigned char clear_count;
  for (clear_count = 0; clear_count <= 11; clear_count++) recv_buf[clear_count] = 0;
  for (i = 0; i < buf_size; i++) {
    recv_buf[i] = uart_receive_char();
    delay(10);
  }
  return (recv_buf[9]);
}

void create_char_file1(void)
{
  Serial.write(0xEF);
  Serial.write(0x01);
  Serial.write(0xFF);
  Serial.write(0xFF);
  Serial.write(0xFF);
  Serial.write(0xFF);
  Serial.write(0x01);
  Serial.write(0x00);
  Serial.write(0x04);
  Serial.write(0x02);
  Serial.write(0x01);
  Serial.write(0x00);
  Serial.write(0x08);
}

void create_char_file2(void)
{
  Serial.write(0xEF);
  Serial.write(0x01);
```

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```
 Serial.write(0x04);
 Serial.write(0x02);
 Serial.write(0x02);
 Serial.write(0x00);
 Serial.write(0x09);
}

unsigned char entry_finger(void)
{
 create_template();
 if (recv_ack(12) == 0x00)
 {
  search_template();
  if (recv_ack(16) == 0x00)
   return 0;
  else
   return 1;
 }
 else
  return 1;
}

void create_template(void)
{
 Serial.write(0xEF);

 Serial.write(0x09);
}

void search_template(void)
{
 Serial.write(0xEF);
 Serial.write(0x01);
 Serial.write(0xFF);
 Serial.write(0xFF);
 Serial.write(0xFF);
 Serial.write(0xFF);
 Serial.write(0x01);
 Serial.write(0x00);
 Serial.write(0x08);
 Serial.write(0x04);
 Serial.write(0x01);
 Serial.write(0x00);
 Serial.write(0x00);
 Serial.write(0x00);
 Serial.write(0xFF);
 Serial.write(0x01);
 Serial.write(0x0D);
}

unsigned char store_finger(void)
{
 read_template_number();
 recv_ack(14);
 page_id1 = recv_buf[10];
 page_id2 = recv_buf[11];
 store_template();
 return (recv_ack(12));
```

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```
}

void read_template_number(void)
{
 Serial.write(0xEF);
 Serial.write(0x01);
 Serial.write(0xFF);
 Serial.write(0xFF);

 Serial.write(0x00);
 Serial.write(0x21);
}

void store_template(void)
{
 Serial.write(0xEF);
 Serial.write(0x01);
 Serial.write(0xFF);
 Serial.write(0xFF);


 Serial.write(page_id1);
 Serial.write(page_id2);

 Serial.write(0x00);
 Serial.write(0x0E + page_id1 + page_id2);
}


void delete_id(unsigned char id)
{
 delete_template(id, 1);
 recv_ack(12);
}


void delete_template(unsigned char page_id, unsigned char no_of_templates)
{
 Serial.write(0xEF);
 Serial.write(0x01);
 Serial.write(0xFF);
 Serial.write(0xFF);
 Serial.write(0xFF);

 //  Serial1.write((unsigned char)((page_id+0x14)>>8));
 //  Serial1.write((unsigned char)(page_id+0x14));

 Serial.write((unsigned char)((page_id + no_of_templates + 0x14) >> 8));
 Serial.write((unsigned char)(page_id + no_of_templates + 0x14));
}

void deletfuncall(void)
{

 static int flag_del = 0;
 unsigned char delflag = 0;


 lcd.clear();
```

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```
lcd.setCursor(0, 0);
lcd.print("ID TO BE DELETE");
delay(2000);
while (digitalRead(SL) != 0)
{
 if (digitalRead(UP) == 0)
 {
  delay(100);
  if (digitalRead(UP) == 0)
   ++flag_del;
  if (flag_del > 10) flag_del = 0;
  while (digitalRead(UP) == 0);
 }
 if (digitalRead(DN) == 0)
 {
  delay(100);
  if (digitalRead(DN) == 0)
   --flag_del;
  if (flag_del < 0) flag_del = 10;
  while (digitalRead(DN) == 0);
 }
 lcd.setCursor(0, 1);
 lcd.print("ID No: ");
 if (flag_del == 10)
 {
  delflag = 1;
  lcd.print("ALL");
 }
 else
 {
  delflag = 0;
  lcd.print(flag_del);
  lcd.print("  ");
 }
}
if (delflag == 1)
{
 do {
  empty_flash();
  recv_ack(12);
 } while (recv_ack(12) != 0x00);
}
else
{
 delete_id(flag_del);
}
lcd.clear();
lcd.setCursor(0, 0);
lcd.print("DELETED");
delay(3000);
 /*Serial1.println("Deleted");
 lcd.clear();
 lcd.setCursor(0, 0);
 lcd.print("   Deleted      ");
 lcd.setCursor(0, 1);
 lcd.print("                ");
 delay(10);
 do {
 empty_flash();
```

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```
    recv_ack(12);
   } while (recv_ack(12) != 0x00);
  */
}

void putfingeronredlight(void)
{
  //Serial1.print("Put finger on ");
  //Serial1.println("Red Light");
  lcd.clear();
  lcd.setCursor(0, 0);
  lcd.print("  PUT FINGER ON ");
  lcd.setCursor(0, 1);
  lcd.print("    RED LIGHT   ");
  delay(1000);
}

void voting(void)
{
  String  buff1 = "", APK = "G9933Q2NB3W8YL2G";
  while (1)
  {
    if (digitalRead(BJP) == 0)
    {
      delay(100);
      ++BJP_count;
      lcd.clear();
      lcd.setCursor(0, 0);
      lcd.print(" YOU VOTED FOR  ");
      lcd.setCursor(6, 1);
      lcd.print("BJP");
      delay(2000);
      break;
    }
    if (digitalRead(JDS) == 0)
    {
      delay(100);
      ++JDS_count;
     lcd.clear();
      lcd.setCursor(0, 0);
      lcd.print(" YOU VOTED FOR  ");
      lcd.setCursor(6, 1);
      lcd.print("JDS");
     delay(2000);
       break;
    }
    if (digitalRead(CONG) == 0)
    {
      delay(100);
      ++CONG_count;
      lcd.clear();
      lcd.setCursor(0, 0);
      lcd.print(" YOU VOTED FOR  ");
      lcd.setCursor(6, 1);
      lcd.print("INC");
      delay(2000);
      break;
    }
    lcd.clear();
```

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```
    lcd.setCursor(0, 0);
    lcd.print(" BJP   INC   JDS");
    lcd.setCursor(0, 1);
    lcd.print("  1     2     3 ");
    delay(2000);
  }

}
void matchingfunction(void)
{
  unsigned char gencount = 0;
  putfingeronredlight();
  while (reactivate_sensor() != 0x00);

  if (entry_finger() == 0x00)
  {
    Serial.println(recv_buf[11]);
    switch (recv_buf[11])
    {
      case 0x00:
        if (f1 == 0)
        {
          f1 = 1;
          lcd.clear();
          lcd.setCursor(0, 0);
          lcd.print("Name: Nandini");
          lcd.setCursor(0, 1);
          lcd.print("ID:23391169803");
          delay(5000);
          lcd.clear();
          lcd.setCursor(0, 0);
          lcd.print("                ");
          lcd.setCursor(0, 1);
          lcd.print("    PLZ VOTE    ");
          delay(1000);
          voting();
          lcd.clear();
          lcd.setCursor(0, 0);
          lcd.print("     THANK      ");
          lcd.setCursor(0, 1);
          lcd.print("      YOU       ");
          delay(1000);
        }
        else
        {
          lcd.clear();
          lcd.setCursor(0, 0);
          lcd.print(" Already Voted  ");
          delay(1000);
        }
        break;
      case 0x01:
        if (f2 == 0)
        {
          f2 = 1;
          lcd.clear();
          lcd.setCursor(0, 0);
          lcd.print("Name: Pooja");
          lcd.setCursor(0, 1);
```

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```
  lcd.print("ID:496229385930");
  delay(5000);
  lcd.clear();
  lcd.setCursor(0, 0);
  lcd.print("   WEL-COME    ");
  lcd.setCursor(0, 1);
  lcd.print("   PLZ VOTE    ");
  delay(1000);
  voting();
  lcd.clear();
  lcd.setCursor(0, 0);
  lcd.print("     THANK     ");
  lcd.setCursor(0, 1);
  lcd.print("      YOU      ");
  delay(1000);
 }
 else
 {
  lcd.clear();
  lcd.setCursor(0, 0);
  lcd.print(" Already Voted  ");
  delay(1000);
 } break;

case 0x02:
 if (f3 == 0)
 {
  f3 = 1;
  lcd.clear();
  lcd.setCursor(0, 0);
  lcd.print("Name: Prabhu");
  lcd.setCursor(0, 1);
  lcd.print("ID:570950891916");
  delay(5000);
  lcd.clear();
  lcd.setCursor(0, 0);
  lcd.print("   WEL-COME    ");
  lcd.setCursor(0, 1);
  lcd.print("   PLZ VOTE    ");
  delay(1000);
  voting();
  lcd.clear();
  lcd.setCursor(0, 0);
  lcd.print("     THANK     ");
  lcd.setCursor(0, 1);
  lcd.print("      YOU      ");
  delay(1000);
 }
 else
 {
  lcd.clear();
  lcd.setCursor(0, 0);
  lcd.print(" Already Voted  ");
  delay(1000);
 }
 break;

case 0x03:
 if (f4 == 0)
```

```
  {
   f4 = 1;
   lcd.clear();
   lcd.setCursor(0, 0);
   lcd.print("Name: Nivedita  ");
   lcd.setCursor(0, 1);
   lcd.print("ID : 262511516468");
   delay(5000);
   lcd.clear();
   lcd.setCursor(0, 0);
   lcd.print("    WEL-COME    ");
   lcd.setCursor(0, 1);
   lcd.print("    PLZ VOTE    ");
   delay(1000);
   voting();
   lcd.clear();
   lcd.setCursor(0, 0);
   lcd.print("     THANK      ");
   lcd.setCursor(0, 1);
   lcd.print("      YOU       ");
   delay(1000);
  }
  else
  {
   lcd.clear();
   lcd.setCursor(0, 0);
   lcd.print(" Already Voted  ");
   delay(1000);
  }
  break;

 case 0x05:
  if (f5 == 0)
  {
   f5 = 1;
   lcd.clear();
   lcd.setCursor(0, 0);
   lcd.print("Name: Aishwarya  ");
   lcd.setCursor(0, 1);
   lcd.print("ID : 820225200896");
   delay(5000);
   lcd.clear();
   lcd.setCursor(0, 0);
   lcd.print("    WEL-COME    ");
   lcd.setCursor(0, 1);
   lcd.print("    PLZ VOTE    ");
   delay(1000);
   voting();
   lcd.clear();
   lcd.setCursor(0, 0);
   lcd.print("     THANK      ");
   lcd.setCursor(0, 1);
   lcd.print("      YOU       ");
   delay(1000);
  }
  else
  {
   lcd.clear();
   lcd.setCursor(0, 0);
```

```
          lcd.print(" Already Voted  ");
          delay(1000);
        }
        break;
      default : delay(1);
    }
  }
  else
  {
    lcd.clear();
    lcd.setCursor(0, 0);
    lcd.print("Finger Not Found");
    lcd.setCursor(0, 1);
    lcd.print("    Try Again   ");
    delay(1000);
  }
}

void empty_flash(void)
{
  Serial.write(0xEF);
  Serial.write(0x01);
  Serial.write(0xFF);
  Serial.write(0xFF);
  Serial.write(0xFF);
  Serial.write(0xFF);
  Serial.write(0x01);
  Serial.write(0x00);
  Serial.write(0x03);
  Serial.write(0x0D);
  Serial.write(0x00);
  Serial.write(0x11);
}

////////////////////////////////main program//////////////////////////////////////
void setup()
{
  Serial.begin(57600);

  lcd.init();
  lcd.backlight();//  pinMode(relay, OUTPUT);
  pinMode(UP, INPUT_PULLUP);
  pinMode(DN, INPUT_PULLUP);
  pinMode(SL, INPUT_PULLUP);
  pinMode(BJP, INPUT_PULLUP);
  pinMode(CONG, INPUT_PULLUP);
  pinMode(JDS, INPUT_PULLUP);
  delay(100);
  //  Serial.println("Wel Come");
  lcd.setCursor(0, 0);
  lcd.print("   Wel-come    ");
  lcd.setCursor(0, 1);
  lcd.print("                ");
  delay(2000);
}

void loop()
{
```

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```
int flag = 0, flag1 = 1;
unsigned char allocatednumber = 0;
delay(200);

while (1)
{
 if (digitalRead(UP) == 0)
 {
  delay(100);
  if (digitalRead(UP) == 0)
   ++flag;
  if (flag >= 3) flag = 0;
  while (digitalRead(UP) == 0);
 }
 if (digitalRead(DN) == 0)
 {
  delay(100);
  if (digitalRead(DN) == 0)
   --flag;
  if (flag < 0) flag = 2;
  while (digitalRead(DN) == 0);
 }
 if (digitalRead(SL) == 0)
 {
  delay(100);
  if (digitalRead(SL) == 0)
   break;
 }
 lcd.clear();
 lcd.setCursor(0, 0);
 lcd.print(" SELECT OPTIONS ");
 lcd.setCursor(0, 1);
 lcd.print(OPTIONSsELaRRY[flag]);
 delay(500);

}

while (1)
{
 if (flag == 0)
 {
  putfingeronredlight();

  while (reactivate_sensor() != 0x00);
  if (entry_finger() != 0x00)
  {
   if (store_finger() == 0x00)
   {
    //Serial1.println("  SUCCESSFULL   ");
    lcd.clear();
    lcd.setCursor(0, 0);
    lcd.print("  SUCCESSFULL   ");
    lcd.setCursor(0, 1);
    lcd.print("                ");
    delay(1000);
    Serial.println("sucess");

    switch (allocatednumber)
    {
```

```
    case 0x00: lcd.clear();
      lcd.setCursor(0, 0);
      lcd.print("Name: Nandini");
      lcd.setCursor(0, 1);
      lcd.print("ID:23391169803");
      delay(5000);
      break;
    case 0x01: lcd.clear();
      lcd.setCursor(0, 0);
      lcd.print("Name:Pooja");
      lcd.setCursor(0, 1);
      lcd.print("ID:496229385930");
      delay(5000);
      break;
    case 0x02: lcd.clear();
      lcd.setCursor(0, 0);
      lcd.print("Name: Prabhu");
      lcd.setCursor(0, 1);
      lcd.print("ID:570950891916");
      delay(5000);
      break;

    case 0x03: lcd.clear();
      lcd.setCursor(0, 0);
      lcd.print("Name: Nivedita");
      lcd.setCursor(0, 1);
      lcd.print("ID : 262511516468");
      delay(5000);
      break;
      case 0x04: lcd.clear();
      lcd.setCursor(0, 0);
      lcd.print("Name: Aishwarya");
      lcd.setCursor(0, 1);
      lcd.print("ID : 820225200896");
      delay(5000);
      break;

    default: lcd.clear();
      lcd.setCursor(0, 0);
      lcd.print("   NOT VALID    ");
      lcd.setCursor(0, 1);
      lcd.print("                ");
      delay(2000);

  }
  ++allocatednumber;
 }
 else
 {
  //  Serial1.println("  UNSUCCESSFULL ");
  lcd.clear();
  lcd.setCursor(0, 0);
  lcd.print("  UNSUCCESSFULL ");
  lcd.setCursor(0, 1);
  lcd.print("                ");
  delay(1000);
 }
}
else
```

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```
    {
     lcd.clear();
     lcd.setCursor(0, 0);
     lcd.print("This FingerPrint");
     lcd.setCursor(0, 1);
     lcd.print("Is Already Exist");
     delay(1000);
    }
   }
   else if (flag == 1)
   {
    deletfuncall();
   }
   else if (flag == 2)
   {
    matchingfunction();
   //      goto up;
   }

  }
}
```

Conclusion:

The biometric voting system was implemented to solve the proximity bottlenecks, unnecessary time delays with very secure and accurate recording of votes. This project was designed to implement a system that will be used for election process. The integration of biometric authentication within the system will provide an efficient way to cast votes, free of fraud, and make the system more trustable, economic and fast as well as enabling the voters to cast their votes from any location as a result of the online voting module which can be accessed from any device with internet connectivity. The use of fingerprint 75 recognition deepens the process of ensuring that the voting mantra – one man, one vote- is fully enforced.

It is seen that the system is fault tolerant at all end points (registration, voting platform and the server). The voting device can last for more than 6 hours which is very sufficient for a quick system like ours. This system will provide boundless voter participation in remote areas with very little or no cost on the voter greatly reducing apathy. Further improvements can be done on the system to increase the credibility of the votes and further reduce proximity issues.

References:

1. “Alaguvel R., Gnanavel G., Jagadhambal K. – "Biometrics using Electronic Voting System with Embedded Security", pp. 1065, 2013”
2. “Arduino – The complete guide to Arduin for beginners by James Arthur”
3. “Exploring Arduino – Tools and technique for Engineering Wizardry by Jeremy Blum”
4. “Arduino project for engineers by Neerparaj Rai”
5. “Handbook of Arduino by Arsanth Natheem”
6. “Arduino – The ultimate guide to Arduino for beginners including Arduino basics, tips, Projects by Tim Warren”
7. “Beginning Arduino" by Michael McRoberts”
8. “Making Things Talk: Using Sensors, Networks, and Arduino to See, Hear, and Feel Your World" by Tom Igoe”
9. "Designing with the Mind in Mind: Simple Guide to Understanding User Interface Design Rules" by Jeff Johnson”
10. “Beginning Arduino" by Michael McRoberts”
11. “Arduino Workshop: A Hands-On Introduction with 65 Projects" by John Boxall”
12. “Programming Arduino: Getting Started with Sketches" by Simon Monk”
13. “Arduino for Dummies" by John Nussey”
14. “Ashok Kumar D., Ummal Sariba Begum T., “A Novel design of Electronic Voting System Using Fingerprint”, International Journal of Innovative Technology & Creative Engineering (ISSN:2045-8711), Vol.1, No.1. pp: 12 19, January 2011.”
15. “International Journal of Computer Applications (0975 – 8887) Volume 145 – No.12, July 2016”

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Original Article

Smartphone Controlled Fingerprint Door Lock System

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Abstract

Currently, the entire globe was infected with COVID-19,and everyone is doing everything they can do to avoid contracting this serious sickness by adhering to social segregations, wearing coverings, using credit-only exchanges, and refraining from contacting anything to prevent the spread of germs with the advancement of technology , traditional looks are becoming relics of the past, while new biometric- based locks and Radio Frequency Identification(RFID) – based locks are becoming increasingly in common. The unique finger impression-based locks, as well as participation record- keeping devices, are used in the vast majority of offices and universities, appropriate to do so. As a result, the proposed system used a solenoid lock to make the door lock. Aside from the equipment, a mobile application is used to inspect and double confirmation, as well as an id, to Arduino through Bluetooth. The entry way lock will be bolted and opened using the smartphone fingerprint sensor.

This concept which is of fingerprint door locker is related to the security issues in the day today life, the physical key can be made as duplicate in very cheap cost and the key can be lost somewhere or key could be stolen .To overcome the issues we can use biometric security gadgets and try improvise the security much more because it can never be stolen it cannot be lost and chance of duplication is very low.

Security has been a major concern for the household and office environment, and for this concern various approaches are in place to address the problem. Most of the major door lock security systems have several loopholes which would be broken down to gain access to the desired places, and it creates a concern for a secure lifestyle and proper working environment.

Introduction

Security is the primary concern and in this busy, competitive world, human cannot find ways to provide security to his confidential belongings manually. Instead, he finds an alternative which can provide a full fledge security as well as atomized. In the ubiquitous network society, where individuals can easily access the same information anytime and anywhere, because of this risk, personal identification technology, which can distinguish between registered legitimate users and imposters, is now generating interest.

Generally, passwords, identification cards and PIN verification techniques are being used but the disadvantage is that the passwords could be hacked a card may be stolen or lost. The most system is fingerprint recognition because a fingerprint of one person never matches the other. Biometrics studies commonly include fingerprint, face, iris voice, signature, and hand geometry recognition and verification. Many other modalities are in various stages of development and assessment. Among these available biometric traits fingerprints proves to be one of the best traits providing good mismatch ratio, high accurate in terms of security and also reliable.

As security is the main concern now a days, by keeping security aspects and other manual mistakes in mind, to solve these problems high secure fingerprint door lock system is to be introduced.

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Materials and Methods:

- The Arduino Uno is an open-source microcontroller board based on the Microchip ATmega328P microcontroller and developed by Arduino.cc [1][2]. The board is equipped with sets of digital and analog input/output (I/O) pins that may be interfaced to various expansion boards (shields) and other circuits [3]. The board has 14 digital I/O pins (six capable of PWM output), 6 analog I/O pins, and is programmable with the Arduino IDE (Integrated Development Environment), via a type B USB cable [4]. It can be powered by the USB cable or by an external 9-volt battery, though it accepts voltages between 7 and 20 volts.
- HC-05 is a Bluetooth module which is designed for wireless communication. This module can be used in a master or slave configuration. HC-05 has red LED which indicates connection status, whether the Bluetooth is connected or not. Before connecting to HC-05 module this red LED blinks continuously in a periodic manner. When it gets connected to any other Bluetooth device, its blinking slows down to two seconds. This module works on 3.3 V. We can connect 5V supply voltage as well since the module has on board 5 to 3.3 V regulator. As HC-05 Bluetooth module has 3.3 V level for Rx/Tx and microcontroller can detect 3.3 V level, so, no need to shift transmit level of HC-05 module. But we need to shift the transmit voltage level from microcontroller to RX of HC-05 module.
- Relay is one kind of electro-mechanical component that functions as a switch. The relay coil is energized by DC so that contact switches can be opened or closed. A single channel 5V relay module generally includes a coil, contacts like normally open (NO) and normally closed (NC). This article discusses an overview of the 5V relay module & it's working. A 5V relay is an automatic switch that is commonly used in an automatic control circuit and to control a high-current using a low-current signal. The input voltage of the relay signal ranges from 0 to 5V.
- The two Channels Relay Module is a convenient board which can be used to control high voltage, high current load such as motor, solenoid valves, lamps and AC load. It is designed to interface with microcontroller such as Arduino, PIC and etc. The relays terminal (COM, NO and NC) is being brought out with screw terminal. It also comes with a LED to indicate the status of relay.
- An audio signaling device like a beeper or buzzer is used which is electromechanical or piezoelectric or mechanical type. The main function of this is to convert the signal from audio to sound.
- Jumpers used are tiny metal connectors which are helpful to close or open a circuit part. They have two or more connection points, which regulate an electrical circuit board. Their function is to configure the settings for computer peripherals, like the motherboard. Suppose your motherboard supported intrusion detection. A jumper can be set to enable or disable it.

Result and Discussions:

1 Arduino Program Code:

Programming Language: C Programming Language.

```
String readString;
#define relay 13
#define buzzer 3
void setup()
{
 Serial.begin(9600);
 pinMode(relay, OUTPUT);
 digitalWrite(relay, LOW);
 pinMode(buzzer,OUTPUT);
 digitalWrite(buzzer,LOW);
}
void siren()
 {
  digitalWrite(buzzer, LOW);
  delay(1000);
  digitalWrite(buzzer, HIGH);
 }
void loop()
{
 while(Serial.available())
 {
  delay(10);
  char c = Serial.read();    //Conduct a serial read
  if (c == '#'){
   break;                //Stop the loop once # is detected after a word
  }
```

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```
  readString += c;              //Means readString = readString + c
 }
  if (readString.length() >0)
  {
   Serial.println(readString);

   if(readString == "f success")
    s{
     siren();
     digitalWrite(relay, HIGH);
     delay(3000);
     siren();
     digitalWrite(relay, LOW);
    }
    readString="";
  }
}
```

2 Code explanation:

The complete code for **Fingerprint Lock using Arduino** is given above. The stepwise description of the code is given below. The Arduino Uno and Bluetooth module communicate via serial communication and this makes the code very simple. Since we are using the Arduino's hardware serial pins (Rx & Tx) and not software serial, we don't need to include a library for Serial Communication. The basic function of the code is to monitor the incoming serial data and compare it with pre-defined conditions, if the fingerprint is authorized then open the lock else keep it locked. So, start the code by declaring a variable to hold the data received from the Bluetooth and define the Arduino pins to which the Relay and buzzer are connected.

Inside the ***setup () function,*** start the serial communication with a baud rate of 9600 and also set the ***pinMode*** for the Relay and buzzer pins. Next, inside the ***loop () function***, check for the availability of data from the Bluetooth module, if the data is available, then read the data and store it in a variable. After that, use an *if* statement to compare it and see if it is a 1 or 0. If the data is 1, then open the lock, and if it's 0, then keep it locked.

Android App:

The app for this project was designed using the Kodular app inventor. Creating an app using Kodular is very simple; you can make an app by combining the blocks according to the flow chart of your project. To create an app with Kodular, navigate to Kodular.io and create an account if you don't have one, Login to your account, and then click on the '***Create Apps'*** option.

After that, you will be taken to the Projects screen. Click on the 'Create Project' button to create a Project. Name the app and click '*Finish*'. The project will be created and you will be taken to the Designer page of the project. Now on the Designer page, add these four components from Components Palette to create a layout for the app: Bluetooth Client, Fingerprint, List Picker, and Image Button. List picker and Button can be found in 'User Interface' while Fingerprint and Bluetooth can be picked from 'Sensors' & 'Connectivity'.

After installing the *.apk* and connecting the hardware as per the circuit diagram, connect the Arduino to the laptop and upload the code (Remove the TX& Rx pins before uploading the code). After that, turn on the Bluetooth of your phone and then pair the Bluetooth module with your phone. Now open the app and click on the Bluetooth icon, and connect with the Bluetooth module. Once the Bluetooth module connects with the app, the Bluetooth icon changes into Lock Icon. After that, touch the fingerprint button and it will ask you to scan your finger on the fingerprint sensor. If the fingerprint is authentic, then it will open the door else the door will remain in a locked position. This is how you can use your smart phone's fingerprint sensor to control a door lock.

3. Software description of fingerprint-based door lock system

ARDUINO IDE (R3)

The open-source Arduino software (IDE) makes is easy to write code and upload it to the board. It runs on windows, MAX OS X, and Linux. The environment is written in java and based on processing and another open-source software. The Arduino integrate Development Environment or Arduino software (IDE) contains a text editor for writing code, a message area, a text console, a toolbar with buttons for common function and a series of menus. It connects to the Arduino and Genuine hardware to upload the program and communication with them.

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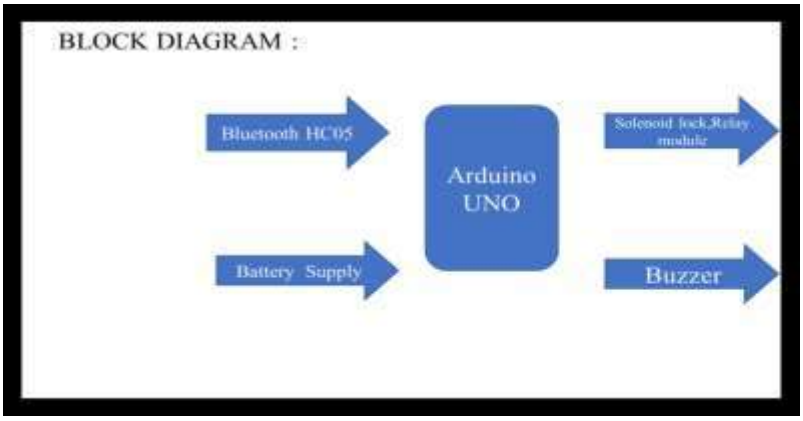

Figure 1. Represents the Block Diagram of Fingerprint Door Lock System.

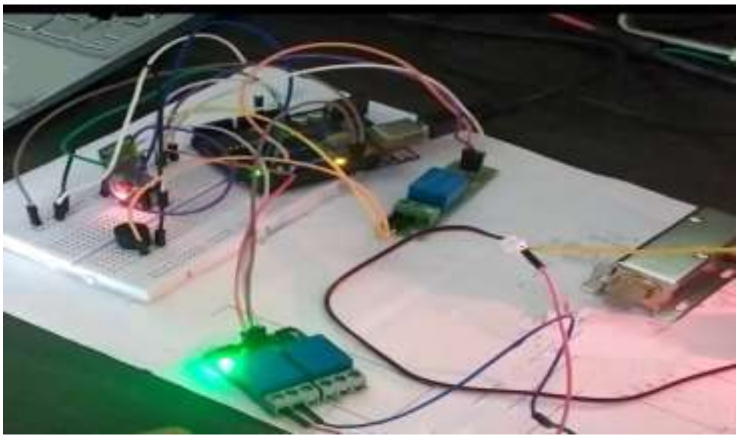

Figure 2. Reperesents the working model of fingerprint door lock system

Arduino UNO R3 developer board is used as a computer to perform the actions.

Bluetooth module is used to produce stimuli. +VCC pin is connected to +5V of Arduino pin and ground pin us connected to ground of Arduino. Tx pin is Bluetooth module is connected to Rx pin of Arduino. Rx pin is connected to Tx pin of Arduino.

A buzzer is used with a relay switch. +VCC of relay is connected to 5V of Arduino and ground pin is connected to ground of Arduino. I/P pin of relay is connected to pin no. 13 of Arduino. Common pin is connected to +5V and NC pin of relay is related to positive of buzzer. Negative pin of buzzer is connected to ground. Solenoid lock is also used with a relay switch. +VCC of relay is connected to 5V of Arduino and ground is connected to ground pin of Arduino. I/P pin is connected to pin no. 3 of Arduino. Common pin of relay is connected to 12V. Positive of solenoid is connected to NC terminal of relay. Negative pin of solenoid is connected to ground.

4 Working of the circuit:

Bluetooth receiver module is interfaced with Arduino UNO R3. Solenoid lock is used as a output and buzzer is used to indicate lock and unlock of the solenoid. Relays are used as switch. Basic connections like +VCC and GND for Bluetooth module and relays are ade.

Pin 3 of the Arduino is connected to input of relay buzzer and Pin 13 is connected to the input pin of the relay of solenoid lock. C language code is written and dumped to the Arduino using Arduino.cc software. Bluetooth keeps interacting with the Arduino with the help of Tx and Rx pins. A signal is sent repeatedly to Bluetooth module to check any Bluetooth connections. A smartphone is connected to a Bluetooth module, android software is used in the smartphone to detect the fingerprint and send a signal. When the software in the smartphone detects a fingerprint (which is already feed/present in the mobile’s data base) successfully the signal is sent to the Bluetooth module. First Pin 3 become HIGH for some seconds which is connected to the buzzer through relay. When this pin becomes HIGH the buzzer is turned ON, indicating that door will be unlocked.

After some seconds Pin 3 becomes ZERO and Pin 13 becomes high which is connected to the relay. When Pin 13 becomes HIGH which is connected to the lock through relay. When Pin 13 becomes HIGH the door is unlocked. After some seconds the pin 3 becomes HIGH again turning ON the buzzer to indicate the door is going to be locked. After a while both pin 3 and pin 13 will become zero, buzzer is turned OFF and the door is locked. Then Bluetooth module is initiated again to detect signal. Above steps are repeated again when true/successful signal is detected.

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5 Applications of the developed Fingerprint door lock system

1. Used in Banks and Offices to secure the vaults door or simply for residential houses door lock system.
2. Fingerprint security system can be used in ATM, fingerprint operated Vehicles.
3. Can be used for voter ID registration.
4. Theft protection.

Conclusion:

Fingerprint door locks are great investment for home or business. It provides great security by providing restrictions to unwanted access. This device increases level of security by adding unique biological features of authorized person. For anyone who wants more security to their homes, fingerprint-based door lock system is best choice. Government agencies are increasingly using biometrics systems in variety. It will become a revolution in future and will set up a mark for the people to access this system for their security.

References:

1. Jigme Yashi, Kazuhiro Mur Matsu. Dual Door Lock System Using Radio-Frequency Identification and Fingerprint Recognition – 2019.
2. Hashem Alnabhi, Yahya Al - naamani, Mohammed Al-madhehagi, Mohammed Alhamzi. Enhanced Security Methods of Door Locking Based Fingerprint - 2020.
3. Rohit Kumar Dubey, Jonathan Goh and Vrizlyn L. Fingerprint Liveness Detection from Single Image Using Low Level Features and Shape Analysis -2016. s
4. Vikas Goyal, Himanshu Jindal Improved finger prints matching miuatiae singular points network -2017
5. Pravjot Kaur, Gagan deep Jagdev Reconnoitring and Instigating Fingerprints as Secure Biometric Technique - 2017
6. Wu Ping, Wu Guichu, XieWebin, Lu Jianguo, Li Peng Remote Monitoring Intelligent System Based on Fingerprint Door Lock – 2010
7. Gudavalli, Monica, Vidya Sagar Novel Door Lock Operation Using Two Staged Smart Security Verification-2019
8. Anu and Bhatia A smart door access system using finger print biometric system – 2014.

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Original Article

Advances in graph theory and its applications

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Abstract

Graph theory is a branch of discrete mathematics which is highly applicable in our daily life, social networks and in computer networks. Graph is collections of vertices and edges and graph theory is studying the graphs in a systematic way. this paper describes the description of graph theory and its applications.

Graph theory has evolved from a foundational mathematical concept into a vital tool for modeling complex, interconnected systems, with recent advances focusing on network analysis, algorithm efficiency, and spectral graph theory. Its applications now span social networks, bioinformatics, logistics, and data science, utilizing structures like nodes and edges to solve optimization, connectivity, and structural analysis problems.

Keywords: *Eulerian Graph, Hamiltonian Graph, Directed Graph, Planar Graph.*

Introduction

Graph theory is a branch of mathematics. which deals with the study of graphs by using mathematical Mathematical Structures, which shows the relationship between the objects. Graph is one of the easiest ways to represent any complex arrangement. It has a wide range Applications in computer science such as algorithms, data structures, Artificial Intelligence, Communication, Engineering and Transportation networks.

In the recent Years the role of Graph Theory expands to solve the Problems regarding cybersecurity, Job sequence Problem, construction of roads, time table making, traffic signals and etc.

Basic Definitions:

- Graph: A Graph G consists of set of vertices V and set of Edges E, that connect pair of Vertices i.e. (V, E).
- Order of a Graph: No. of Vertices Present in a Graph is called Order of a Graph.
- Size of a Graph: No. of Edges Present in a graph is called size of a graph.
- Directed Graph: A Graph ion which each edge has its own direction, indicated by an arrow.
- Simple Graph: A Simple Graph Which has no loop and no Multiple edges between the same pair of vertices.
- Hamiltonian Cycle: It is the closed loop which visits every vertex only once.
- Hamiltonian Graph: A Graph which contains Hamiltonian Cycle.
- Eulerian Cycle: It is the closed loop which visits every edge only once.
- Eulerian Graph: A Graph which contains Eulerian Cycle.
- Planar Graph: A Graph can be drawn without crossing any edges is called Planar graph.
- Cover: A Line x= (u, v) of a graph G, Covers the points u&v i.e a point and a line are said to cover each other if they are incident.
- Point Cover: A set of points which covers all the lines of a graph G is called Point Cover of graph G.

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- Line Cover: The set of lines which covers all the Points of a Graph is called line cover.
- Point Independent Set: A set points in a graph G is said to be an independent set if no of them are adjacent.
- Point Independent Number: The Largest number of points in an independent set is Point Independent number.
- Line Independent Set: A set Lines in a graph G is said to be a Line independent set if no of them are adjacent.
- Line Independent Number: The Largest number of elements in the Line independent set is Line Independent number.

Applications of Graph Theory:

- **Graph Coloring and Scheduling**: A Mathematical technique where adjacent vertices are assigned different colors or labels. This Graph coloring helps in time table making and in Maps coloring.
- **Topology and Knot Theory**: In Mathematics, Graph Theory is used to analyze connectivity and particulary in knot theory, to study the properties of knots and their embeddings in 3D space.
- **Social Network Analysis**: Graphs model social structures where individuals (vertices)are linked by relationships (edges), helping in community detection and stydying influence flows.
- **Computer Networks**: In **computer networks**, graph theory plays a crucial role in designing network topologies, developing routing algorithms, and optimizing data transmission. It helps in determining efficient paths for data packets to travel from source to destination, thereby improving network efficiency and reliability.
- **Transportation Network**: Graph theory is essential in modeling **transportation networks,** including road networks, railway systems, and flight routes. It enables efficient route planning, traffic optimization, and resource allocation by analyzing the connectivity and distances between locations within the network.
- **Biological Network**: Models chemical molecular structures, genetic structures, and protein interactions.
- **Job Sequence Problem**: The job sequencing problem in mathematics and operations research involves ordering a set of tasks on machines to optimize specific criteria, such as maximizing total profit under deadlines or minimizing total processing time. Common approaches include using greedy Technique.
- **Here is an example:** A Number of Jobs J1, J2, _ _ _ _ _ Jn Have to be Proceed by one person.

	J1	J2	J3	J4
Profit	50	15	10	25
Deadline	2	1	2	1

There are 4 Jobs (J1, J2, J3, J4) With these jobs there are 2 parameters profit & deadline. The meaning of the deadline is in the given month only we have to complete that work, means for J2 it is 1 means in the first month only we have to complete that work, we are not supposed to leave that work for 2nd month.

There are some assumptions for this example,

- we are working on a uniprocessor system (Means only 1 person have to do all 4 jobs).
- Second assumption is that preemption is not allowed. (Means if a jb starts then that job will be completely completed by you then only you are allowed to start the next one)
- Every job will take 1 unit of Time that may be 1 month, 1 day, 1-year etc. let us assume it as 1 month.
  Now we have to sequence the jobs in the form of getting more profit.

At first, we have to make a Gant Chart and it means it is the max. deadline number, in the given example we are having maximum 2 months to complete all jobs.

0 1 2

Now it is very important to understand the meaning of deadline, in the given problem deadline is 2 means you are having 2 months to comple your jobs but each job you have to complete in the single month only.
Now looking at the profit I have scheduled J1 first means I have comple J1 first then I will Complete J3.

J1	J3

0 1 2

50+10=60

If we observe we will get 60 as our Profit, now we have to clarity that is it our maximum profit, if not then go for next Gant chart.

J4	J1

0 1 2

25+50=75

This is the optimal answer which is the maximum profit of all the jobs. like this we can find the problem for Job Sequence problem.

- **Making Road System one way**: In graph theory, modeling a one-way road system involves converting an undirected graph (representing two-way streets) into a **directed graph (digraph),** where edges are assigned specific orientations/arrows to indicate travel direction. This conversion is used to study traffic configurations, shortest paths.
- **Ranking the participants in the tournaments:** Tournament ranking in graph theory involves ordering vertices (participants) in a complete directed graph to minimize inconsistencies, often by minimizing "backward arcs" (arcs pointing opposite to the ranking order). Key methods include scores (out-degree/wins), Finding Hamiltonian paths in transitive tournaments, or maximizing total wins in a transitive closure.

Conclusion:

Totally graph theory has a wide range of applications. This paper has explored the, advances in graph theory, highlighting its critical role in modern computing, AI, and networking. The integration of advanced algorithms, such as those for large-scale network optimization and, dynamic graph analysis, provides essential solutions for complex real-world problems. As, graph-based AI models and, interdisciplinary applications continue to expand, graph theory remains a crucial tool for modeling connectivity, optimizing data structures, and uncovering insights across diverse scientific disciplines. the evolution of graph theory from simple, topological representations to complex, algorithmic applications demonstrates its enduring relevance. Its ability to represent relationships in, large-scale, data-driven systems guarantees its continued importance in bridging theoretical mathematics and practical engineering.

References:

1. F. Harary Graph Theory, Addision Wesley, Reading Mass 1969.
2. G. Chartrand, L. Lesnisk and P. Zhang; Graph theory and diagraphs: Chapman and Hall, 2011.
3. G. Chartrand and and P. Zhang; Introduction to Graph Theory, McCraw Hill, 2005.

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Original Article

AI in Society, Ethics, Governance and Education

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Abstract

Artificial Intelligence (AI) has become a major technological advancement that has revolutionized all areas of our everyday lives through an overall impact; from education, to the health sector, to the way in which we administer government services to the citizens. Through its utilization of efficient processes and innovation, AI adds to the new opportunities provided by improved efficiency and inclusive access across a variety of sectors and industries. On the other hand, AI raises significant challenges that will require addressing a variety of ethical, legal, and social issues such as fairness, transparency, accountability, privacy, and human autonomy. This research paper will be an in-depth examination of the significant impact of AI on the creation and future of society through examining the impacts of AI in the following areas: ethics, governance, and education. Additionally, this research paper will analyze the implementation of ethical guidelines and policies for AI development and the implementation of AI by governments for the development of policies and procedures used for public administration. Finally, this research paper will examine how the practice of teaching and learning, as well as how educational institutions administer their own operations, has transformed through the use of AI technology. Based on current research in the field, this research paper will provide evidence that the benefits of AI will only be achieved when an established set of ethical standards, ongoing oversight of ethical standards, and inclusion in how AI is being used in the educational system are utilized correctly. In summary, the authors believe that AI is to be further utilized by government decision-makers, educators, and technological experts to promote the well-being and continued sustainable growth of society.

Keywords: *Artificial Intelligence, Ethics, Governance, Education, Responsible Artificial Intelligence, Society.*

Introduction

Artificial Intelligence systems can perform tasks that human intelligence typically does, such as learning and reasoning. Advances in machine learning and data analytics have allowed for AI systems to be used in many different sectors, including health care, finance, transportation, and education.

The use of AI can improve efficiency and decision making; however, it also creates ethical concerns (e.g., bias), governance issues (eg. lack of transparency), data privacy risks, and job displacement. As the use of AI grows, there will be a need for accountability and responsible regulation.

This paper will analyse the impact of AI on education through three lenses of ethics, governance, and education; it will identify key challenges and policy responses to those challenges as well as the overall impact of AI on educational systems.

Artificial Intelligence in Society

AI systems can perform tasks that are generally carried out by human intelligence such as learning and reasoning. The growth of machine learning and data analytics has opened up many sectors to the application of AI which include the health care, finance, transportation and educational sectors.

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AI provides the ability to improve both efficiency and decision making but it also creates new ethical challenges (e.g., bias) and governance challenges (e.g., lack of transparency), poses data privacy risks and produces job loss. As the use of AI continues to grow there will be a need for accountability and responsible regulation.

The objective of the paper is to explore the effects of AI on the field of education through three lenses: ethics, governance and education. In addition, it will elaborate on important challenges pertaining to AI in education and provide suggested policy responses to address those issues as well as the overall impact AI has had on education systems.

Ethical Dimensions of Artificial Intelligence

Responsible AI Development & Deployment Starts with Ethical Considerations. The term 'AI ethics' refers to the effort to ensure that AI technologies adhere to human values and principles of fundamental rights. Many significant ethical principles have been outlined in both the academic and policy realms.

1. Fairness and Non-Discrimination

AI systems should be constructed in a manner that avoids introducing biased or discriminative outcomes into the decision-making process. Due to the usage of historical data by AI models when training, bias may already be present in the training data; hence a system learning from this data can also learn bias. As a result, careful data selection, bias detection methods, and constant monitoring of all deployed AI systems must take place to ensure the success of this ethical principle.

2. Transparency and Explainability

A “black box” approach is dominating the development of many AI models today, particularly deep learning models, which make it very difficult for any individual to understand how the model arrived at its ultimate decision or output. Because of this black box phenomenon, transparency and explain ability must be included into all AI systems if a user or data consumer is to trust and accept the outcome generated by the AI system in question. The intent of explainable AI approaches is to allow users and data consumers to interpret the results of an AI system, both amateur and professional users.

Privacy & Data Protection

The use of AI systems frequently involves the acquisition of large amounts of personal information. There are significant privacy concerns associated with collecting, storing, and utilising this type of information. Ethical AI should adhere to all relevant data protection principles, as well as provide individuals with the opportunity to provide informed consent and to safely handle their personal information.

Responsibility & Human Oversight

Establishing who is liable for AI-related decisions represents a very important ethical issue. We must be able to clearly define accountability so that the responsible parties can be held liable if AI systems produce negative consequences. To help resolve this issue, human-in-the-loop (HITL) approaches focus on implementing substantial human oversight when making important decisions instead of relying solely on automated processes.

Human Autonomy & Dignity

AI should augment human decision-making capability but not compromise human autonomy. Over-dependency on automated methods of decision making can significantly reduce one's ability to make decisions on their own or perform critical thinking. Ethical AI design will emphasise human dignity and will ensure that AI technology is an aid to human judgment rather than an independent source of judgment.

Ai Governance and Policy Frameworks

AI governance includes the elements which help to govern both the development and application of AI technology includes the governing structures, policies and practices associated with the emergence of artificial intelligence. The ultimate goal of good AI governance is to find the appropriate balance between AI innovation and risk management, while at the same time operating in an ethical manner.

A. AI Policies at the National or International Level

Numerous governments have developed national AI strategies in order to foster AI innovation as well as address various concerns impacting society at large. Myriad aspects of these policies include ethical guidelines, research investment, capacity building, and safety regulations. Various international organizations have also established common principles to promote the establishment of trustworthy AI systems globally.

B. Approaches to AI Regulation

AI has varying degrees of regulatory implementations across jurisdictions (i.e., from many-sectoral guidelines to comprehensive legal frameworks). Primary goals of governing rules generally include protecting fundamental human rights, assuring that there is proper transparency surrounding the application of AI, and mitigating any potential risks of utilizing AI. Increasingly, regulators are seeking to achieve a "risk-based" approach to regulation – whereby AI systems deemed to pose more risk require stricter regulatory requirements to be imposed upon their deployment.

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C. AI in Public Governance

Numerous stateentities are implementing artificial intelligence as aid to delivery of public services and also as an aid in conducting analysis of policy decisions and improving administrative efficiency. AI based tools are utilized in supporting decision-making in the areas of property/personal tax collection, public assistance program distribution, urban development and planning, and public safety law enforcement. There are concerns raised over the use of AI related to surveillance, discrimination, and accountability to the citizens through the democratic process; therefore creating transparent mechanisms for governance while also ensuring citizen participation is vital for maintaining citizen trust in the government.

D. Institutional Governance and Organizational AI

The implications of AI on governance within the individual organization include a change in the decision-making processes by automating some processes and by changing the existing power relationships among different levels of the organization. Institutions must establish internal governance frameworks relating to AI which will define their ethical standards, data management policies and accountability roles. There must be a strong commitment from leadership within the institution, as well as the involvement of all stakeholders through the responsible use of artificial intelligence.

Ai In Education

Education is rapidly evolving through the potential of artificial intelligence (AI). Through the use of AI technology, both teaching methods and administrative management at colleges and universities are changing.

A. Customized Learning and Teaching Support

These digital learning funds allow for customized education by personalizing learning content, pacing and assessments based on the individual. The use of intelligent tutor systems provides real-time support and feedback for students and helps to maintain student participation. AI can also help teachers with evaluation, developing content, and evaluating learning analytics.

B. Evaluation and Evaluation of Learning Analytics

AI allows for data-driven evaluations of students by identifying trends in student results and predicting the likelihood of students experiencing learning difficulties. Learning analytics can be used to identify early intervention strategies and provide support for evidence-based teaching practices. However, there are potential ethical implications in the evaluation process related to protecting student data, profiling students and the use of AI algorithms which inherently have a bias.

C. Educational Governance

AI is not only impacting how we educate students, but it is also influencing how educational institutions operate. AI is being used to make administrative functions more efficient, allocate resources to their most effective use, and assist in the strategic planning process. AI analytics are being used to assist in decision making processes relating to admission to schools, curriculum development and quality control. However, there are numerous obstacles to using AI related to transparency, data safety and ensuring equitable access.

D. Equity and Access in AI-Enabled Education

AI can help democratize education, but unequal access to digital infrastructure and technology could create further inequality. Therefore, to ensure that educational innovation reaches all, there must be inclusive AI strategies that support marginalized communities.

Intersections Of Ethics, Governance and Education

The intersections of ethics, governance and education indicate that integrated approaches to AI development will require ethical principles to inform governance frameworks and education that supports individuals in understanding and using AI ethically. Educational institutions provide both a user and shaper of AI technologies.

By embedding ethics into curricula on AI, educational institutions can help build the critical awareness of future professionals who work with AI. Likewise, by adopting transparent governance practices, educational institutions will set an example of how to use AI ethically. Collaboration among policymakers, educators, technologies and civil society is also critical to ensuring that the development of AI aligns with the societal values.

Challenges And Future Directions

There have been advancements made in the field of AI but many challenges still exist. By not addressing technical, standardization and ethical issues, adoption of responsible use of AI is limited by these variables. Policies often do not keep up with the fast pace of technological advancement, thus leaving gaps in regulation.

Future directions in responsible AI will be based upon developing standards for ethical auditing, conducting interdisciplinary research, and cooperating internationally through AI governance. Education systems must establish AI literacy for youth, include ethics education as part of AI curriculum, and create opportunities for lifelong learning to prepare society for an AI future.

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Conclusion

AI will transform society in a significant fashion regarding governance systems, ethics and education practices. AI has the potential to be a transformational tool, but it can only accomplish its full potential if AI is designed and governed responsibly. This paper has explored ways to understand AI through ethics, governance and education as the three areas cannot be isolated from each other.

Responsible use of AI requires a strong ethical foundation, an open governance model and an inclusive approach to education. To use AI as a vehicle for social good we need to collaborate with all key stakeholders and align the development of AI to human values. As AI continues to change, we must continually examine, regulate and educate on AI to maximize the benefits of technological advancement toward equitable and sustainable growth.

References

1. G. Mariam, L. Adil, and B. Zakaria, “The Integration of Artificial Intelligence (AI) into Education Systems and Its Impact on the Governance of Higher Education Institutions,” International Journal of Professional Business Review, vol. 9, no. 12, 2024.
2. UNESCO, “Ethical Implications of Artificial Intelligence in Education,” UNESCO Publishing, 2022.
3. OECD, “Artificial Intelligence in Society,” OECD Publishing, 2019.
4. European Commission, “Ethics Guidelines for Trustworthy AI,” 2019.
5. R. Holmes, M. Bialik, and C. Fadel, “Artificial Intelligence in Education: Promises and Implications for Teaching and Learning,” Center for Curriculum Redesign, 2019.

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Original Article

Production of Bio fuel from Fruit Waste

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Abstract

Bioethanol is a renewable biofuel produced from carbohydrate-rich agricultural residues and fruit waste. This study investigated bioethanol production from sweet potato, pineapple, and jackfruit waste using Saccharomyces cerevisiae via acid hydrolysis and fermentation. Fruit wastes were oven-dried, powdered, and hydrolyzed with various concentrations of sulfuric acid (2–10%). Hydrolysates were neutralized, and total carbohydrates and glucose contents were estimated. Fermentation was performed, and ethanol content was quantified using the dichromate method. Maximum ethanol yield was obtained from pineapple waste (0.22%), followed by jackfruit (0.21%) and sweet potato (0.11%). The study demonstrates that fruit wastes are a cost-effective and environmentally sustainable feedstock for bioethanol production. Results were compared with previous studies to validate the efficiency and feasibility of using fruit wastes as renewable energy sources.

Keywords: *Bioethanol, Fruit waste, Fermentation, Saccharomyces cerevisiae, Acid hydrolysis*

Introduction

Bioethanol (C_2H_5OH) is a clear, volatile, and flammable liquid produced via microbial fermentation of sugar-rich substrates. It is a sustainable alternative to fossil fuels and contributes to reducing environmental pollution. Agricultural and fruit wastes, including sweet potato, pineapple, and jackfruit, contain high levels of carbohydrates (starch and simple sugars) and are abundant in local markets, making them an ideal substrate for bioethanol production. Polysaccharides in these wastes are hydrolyzed into fermentable sugars using enzymatic or acid hydrolysis, and Saccharomyces cerevisiae ferments the sugars into ethanol. Yeast is widely employed due to its high ethanol productivity and adaptability to diverse substrates. This study aims to utilize locally available fruit wastes to produce bioethanol efficiently, while evaluating sugar content, fermentation potential, and alcohol tolerance of the yeast.

Review of Literature

Bioethanol production from lignocellulosic and carbohydrate-rich biomass has been extensively studied as a sustainable alternative to conventional fuels. Ackerson et al. (1981) demonstrated that two-stage acid hydrolysis improves sugar recovery and ethanol yield by optimizing hydrolysis conditions. Hossain and Fazliny (2010) reported bioethanol production from pineapple waste and highlighted its potential as a renewable fuel. Chandel et al. (2007) discussed the economic and environmental impacts of bioethanol production technologies, emphasizing substrate choice, process efficiency, and operational scale. Kumar et al. (2015) reviewed biomass energy in India and concluded that fruit and agricultural wastes are abundant and carbohydrate-rich, making them suitable feedstocks for fermentation. Kumoro et al. (2012) studied jackfruit juice fermentation using baker's yeast and reported that proper control of sugar concentration and yeast inoculum is critical for ethanol yield.

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Rani et al. (2019) demonstrated that optimization of hydrolysis parameters such as acid concentration and temperature enhances fermentable sugar release from starchy wastes. Prasad et al. (2018) emphasized that non-edible fruit parts provide a low-cost, environmentally sustainable substrate for microbial bioethanol production. Hughes et al. (2009) highlighted that genetically enhanced yeast strains can tolerate higher ethanol concentrations and improve fermentation efficiency.

Collectively, these studies suggest that fruit wastes reduce environmental burden while providing a renewable, low-cost substrate for bioethanol production. This study builds on these findings by evaluating sweet potato, pineapple, and jackfruit wastes for ethanol production using Saccharomyces cerevisiae, analyzing sugar content, fermentation efficiency, and yeast alcohol tolerance.

Materials and Methods

1 Materials

- **Fruit wastes:** Sweet potato, pineapple, jackfruit (collected from local markets, Karad)
- **Chemicals:** Sulfuric acid (H2SO4), sodium hydroxide (NaOH), peptone, phenol, DNSA reagent
- **Microorganism:** *Saccharomyces cerevisiae* (isolated from baker's yeast)

2 Sample Preparation

Collected fruit wastes were washed, chopped, oven-dried (24–48 hrs), powdered, and stored in airtight containers.

3. Isolation of Yeast

Yeast was enriched in Sabouraud's broth, plated on Sabouraud's agar, and characterized morphologically and Gram-stained to confirm identity as Saccharomyces cerevisiae.

4 Acid Hydrolysis

Powdered fruit wastes (1 g) were hydrolyzed with 20 ml of sulfuric acid at 2%, 4%, 6%, 8%, and 10% concentrations, autoclaved at 121°C for 20 min, cooled, filtered, and neutralized with NaOH.

5 Sugar Estimation

- Total carbohydrates: Phenol-sulfuric acid method, absorbance at 490 nm.
- Glucose content: DNSA method, absorbance at 540 nm.

6 Fermentation

Neutralized hydrolysates supplemented with 1.6 g peptone were inoculated with 2 ml yeast culture and incubated. Ethanol production was quantified using the dichromate method.

7 Minimum Inhibitory Concentration (MIC)

Alcohol tolerance of yeast was determined by incubating Saccharomyces cerevisiae in Sabouraud's broth with 10–50% ethanol concentrations and observing growth turbidity after 24 h.

Results and Discussion

1 Yeast Morphology

The yeast isolate displayed typical Saccharomyces cerevisiae characteristics, confirming suitability for fermentation.

Table No 1 Results of morphological and cultural characteristics of yeast isolate

Size	Shape	Margin	Elevation	Colour	Opacity	Consistency
2 mm	Circular	Regular	Flat	White	Opaque	Moist

2 Carbohydrate and Glucose Estimation

Total carbohydrate content was highest at 2% H2SO4 hydrolysis. Maximum glucose concentration was observed from jackfruit at 6% H2SO4 hydrolysis.

Table No 2 Results of estimation of total carbohydrate of sweet potato

Sr. No	Hydrolysate (ml)	D/W (ml)	Phenol (ml)	Conc. H_2SO_4 (ml)	Boiling Water Bath at 10 Mins.	O.D at 490 nm				
						2%	4%	6%	8%	10%
1	0.0	4.0	1	5		0.0	0.0	0.0	0.0	0.0
2	0.1	3.9	1	5		1.03	0.43	0.16	0.21	0.12
3	0.2	3.8	1	5		1.27	0.78	0.52	0.26	0.15
4	0.3	3.7	1	5		1.29	0.86	0.67	0.39	0.28
5	0.4	3.6	1	5		1.33	0.94	0.73	0.62	0.36
6	0.5	3.5	1	5		1.34	1.00	0.82	0.66	0.41
7	0.6	3.4	1	5		1.14	1.14	0.96	0.79	0.56
8	0.7	3.3	1	5		1.54	1.25	1.00	0.82	0.65
9	0.8	3.2	1	5		1.24	1.33	1.12	0.87	0.66
10	0.9	3.1	1	5						

Table No 3 Result of estimation of total carbohydrate of pineapple

Sr. No	Hydrolysate (ml)	D/W (ml)	Phenol (ml)	Conc. H_2SO_4 (ml)		O.D at 490 nm				
1	0.0	4.0	1	5	Boiling Water Bath at 10 Mins.	2%	4%	6%	8%	10%
2	0.1	3.9	1	5		0.0	0.0	0.0	0.0	0.0
3	0.2	3.8	1	5		0.28	0.27	0.27	0.28	0.23
4	0.3	3.7	1	5		0.47	0.43	0.45	0.55	0.37
5	0.4	3.6	1	5		0.62	0.58	0.52	0.53	0.55
6	0.5	3.5	1	5		0.71	0.67	0.62	0.67	0.57
7	0.6	3.4	1	5		0.73	0.75	0.66	0.71	0.63
8	0.7	3.3	1	5		1.14	1.14	0.96	0.79	0.56
9	0.8	3.2	1	5		1.54	1.25	1.00	0.82	0.65
10	0.9	3.1	1	5		1.24	1.33	1.12	0.87	0.66

Table No 4. Result of estimation of total carbohydrate of jack fruit

Sr. No	Hydrolysate (ml)	D/W (ml)	Phenol (ml)	Conc. H_2SO_4 (ml)		O.D at 490 nm				
1	0.0	4.0	1	5	Boiling Water Bath at 10 Mins.	2%	4%	6%	8%	10%
2	0.1	3.9	1	5		0.0	0.0	0.0	0.0	0.0
3	0.2	3.8	1	5		0.44	0.17	0.18	0.13	0.22
4	0.3	3.7	1	5		0.47	0.32	0.22	0.14	0.26
5	0.4	3.6	1	5		0.54	0.26	0.26	0.20	0.28
6	0.5	3.5	1	5		0.49	0.24	0.29	0.22	0.30
7	0.6	3.4	1	5		0.49	0.22	0.32	0.25	0.33
8	0.7	3.3	1	5		0.51	0.21	0.40	0.32	0.34
9	0.8	3.2	1	5		0.53	0.20	0.42	0.39	0.42
10	0.9	3.1	1	5		0.55	0.21	0.55	0.42	0.45

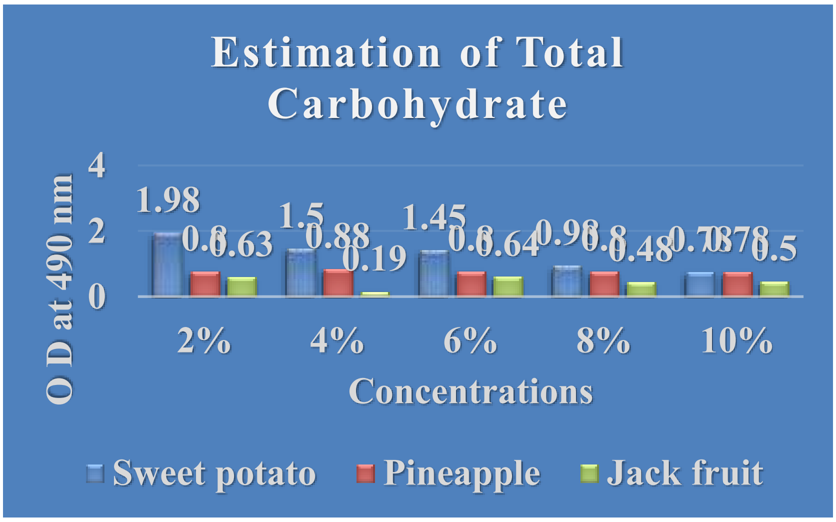

Table No 5 Estimation of alcohol by Dichromate method of sweet potato

Concentrations	Amount of alcohol estimate	
	24 hrs	48 hrs
2%	0.05	0.07
4%	0.05	0.08
6%	0.07	0.08
8%	0.06	0.09
10%	0.07	0.11

Table No: 6 Estimation of alcohol by Dichromate method of Pineapple

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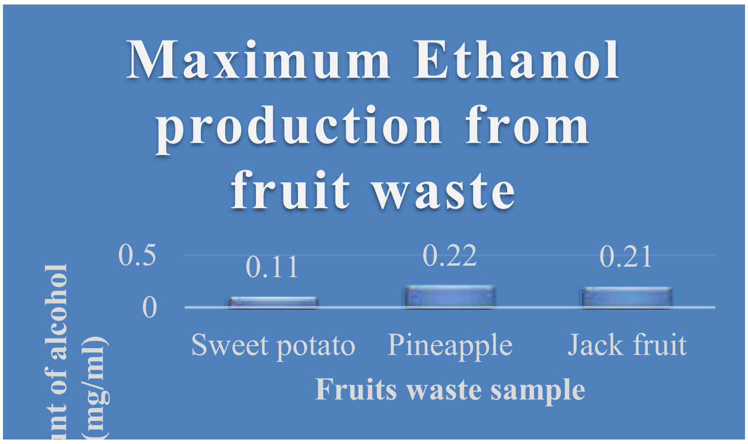
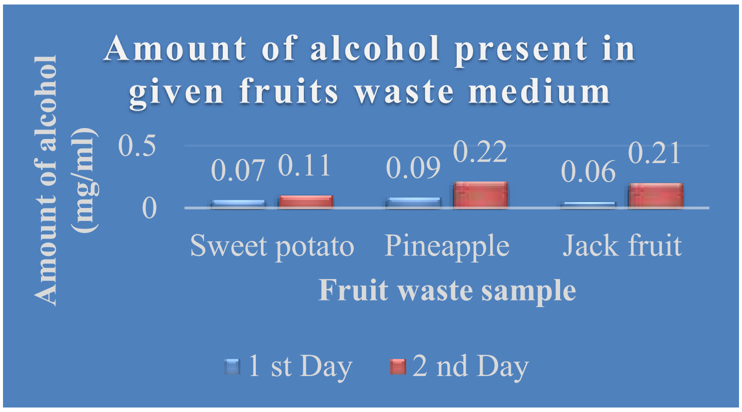
Concentrations	Amount of alcohol estimate	
	24 hrs	48 hrs
2%	0.06	0.14
4%	0.06	0.17
6%	0.07	0.18
8%	0.07	0.19
10%	0.09	0.22

Table No: 4.7 Estimation of alcohol by Dichromate method of Jack fruit

	24 hrs	48 hrs
2%	0.06	0.10
4%	0.06	0.13
6%	0.05	0.15
8%	0.05	0.17
10%	0.06	0.21





Minimum Inhibitory Concentration of alcohol

Minimum Inhibitory Concentration	2%	4%	6%	8 %	10 %	2%	4%	6 %	8%	10%	2%	4%	6%	8%	10%
10%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
20%	+	++	++	-	-	-	-	-	-	-	-	-	-	-	-
30%	+	++	++	-	-	++	++	+ +	++	++	-	-	+	+	+
40%	-	-	-	-	-	-	+	-	+	-	-	-	-	-	-
50%	-		-	-	-	-	-	-	-	-	-	-	-	-	-

(- Negative, + **Slightly** Positive, ++ Positive)

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3 Bioethanol Production

Pineapple waste yielded the highest ethanol (0.22%), followed by jackfruit (0.21%) and sweet potato (0.11%). Lower yields from sweet potato may be due to reduced fermentable sugar content.

4 Alcohol Tolerance (MIC)

Saccharomyces cerevisiae tolerated up to 30% ethanol, indicating ethanol tolerance limits.

5 Literature Integration

These results confirm that fruit waste is an efficient and economical substrate for bioethanol production. Optimized hydrolysis and fermentation conditions enhance sugar recovery and ethanol yield, consistent with global literature on sustainable biofuel production.

Conclusion

The present study establishes that fruit wastes such as pineapple, jackfruit, and sweet potato can be effectively utilized for sustainable bioethanol production using *Saccharomyces cerevisiae*. Among the substrates tested, pineapple waste yielded the highest ethanol output (0.22%), followed closely by jackfruit (0.21%) and sweet potato (0.11%). Acid hydrolysis at lower concentrations (2–6%) proved optimal for sugar release, enhancing fermentation efficiency. Beyond these findings, this research highlights broader implications: implementing such bioethanol production processes at industrial scales could significantly reduce fruit waste disposal challenges, mitigate environmental pollution, and promote renewable energy adoption. Integration of these methods with local agricultural waste management systems offers an economically viable and environmentally sustainable approach for rural and urban areas alike. Future research should focus on optimizing fermentation parameters, exploring co-fermentation of mixed fruit wastes, and investigating genetic enhancements of yeast strains to increase yield.

References

1. Ackerson M, Ziobra M, Gaddy JL. Two-stage acid hydrolysis of biomass. Biotechnol Bioeng Symp. 1981; 11:103-112.
2. Chandel AK, Chan ES, Rudravarat R, Naram LM, Ravindra P. Economics and environmental impact of bioethanol production technologies. Biotechnol Mol Biol Rev. 2007;2(1):14-32.
3. Demirbas A. Bioethanol from cellulosic materials & renewable motor fuel from biomass. Energy Sources. 2005; 27:327-337.
4. Hossain ABMS, Fazliny AR. Creation of alternative energy by bioethanol production from pineapple waste and usage as engine fuel. Afr J Microbiol Res. 2010;4(9):813-819.
5. Hughes SR, Hector RE, Rich JO, Qureshi N, Bischoff KM, et al. Automated yeast mating protocol to improve ethanol-producing yeast strains. J Assoc Lab Auto. 2009;14(4):190-199.
6. Kumar A, Kumar N, Baredar P, Shukla A. Biomass energy resources, potential, conversion and policy in India. Renew Sustain Energy Rev. 2015; 45:530-539.
7. Kumoro AC, Rianasari D, Pinandita APP, Retnowari DS, Budiyati CS. Preparation of wine from jackfruit juice using baker's yeast. World Appl Sci J. 2012; 16:1262-1268.
8. Prasad R, Verma H, Chaurasia D. Bioethanol production from fruit wastes: A review. Int J Environ Sci Technol. 2018; 15:2617–2628.
9. Rani S, Singh V, Sharma A. Optimization of acid hydrolysis for bioethanol production from starchy wastes. Bioresour Technol Rep. 2019; 7:100285.

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Original Article

Green Chemistry principles and applications in Karnataka's Sugar Industry

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Abstract

This research paper examines how green chemistry can transform Karnataka's sugar industry by reducing environmental impact, improving resource efficiency, and enhancing socio-economic outcomes. Using a mixed-method case study approach, it integrates sectoral context, environmental challenges, and practical green interventions across milling, distillery, and co-product streams (bagasse, molasses, press mud). The study proposes measurable indicators and policy pathways to scale sustainable practices across Karnataka's mills and allied units. It situates findings within documented challenges and opportunities in the state's sugar sector and the broader environmental footprint of Indian sugar industries.

Introduction

Chemistry has long been a driver of industrial progress, but its conventional practices often carried hidden costs: pollution, depletion of natural resources, and occupational hazards. The emergence of green chemistry in the late 1990s, through the work of Anastas and Warner, marked a paradigm shift. Instead of treating waste after it is generated, green chemistry emphasizes designing processes that prevent waste at the source. Its twelve principles — ranging from atom economy to inherently safer chemistry — provide a methodological framework for rethinking chemical science.

Sustainable chemistry builds on this foundation but broadens the scope. It situates chemical innovation within global sustainability goals, including climate action, circular economy, and social equity. While green chemistry is process-oriented, sustainable chemistry is outcome-oriented, ensuring that innovations contribute to long-term ecological and social well-being.

Sugar chemistry**,** traditionally focused on sucrose extraction, crystallization, and fermentation, now intersects with these paradigms. In India, the sugar industry is a major agro-based sector, and Karnataka is one of its leading producers. This makes the state's sugar industry an ideal case study to examine how green and sustainable chemistry principles can be operationalized in practice.

Conceptual Relationships

Green chemistry and sustainable chemistry are often conflated, but their relationship is complementary. Green chemistry is process-oriented, focusing on cleaner reactions and safer products. Sustainable chemistry is outcome-oriented, embedding these processes within global sustainability frameworks such as the UN Sustainable Development Goals. Sugar chemistry provides the substrate where these principles converge. For example, molasses fermentation into bioethanol demonstrates atom economy and renewable feedstock use, while its integration into India's ethanol blending program situates it within sustainable energy policy. Thus, sugar chemistry acts as a bridge between methodological innovation and systemic sustainability.

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Green Chemistry Principles in Sugar Chemistry

Table 1. Green Chemistry Principles and Applications in the Sugar Industry

This table links each principle to a practical example in Karnataka's sugar mills.

Green Chemistry Principle	Application in Sugar Industry	Relevant Material/Process
Prevention	Effluent minimization in processing	Effluent treatment
Atom Economy	Fermentation of molasses to ethanol	Molasses
Less Hazardous Synthesis	Anaerobic digestion of effluents	Effluent
Designing Safer Chemicals	Use of non-toxic flocculants in clarification	Juice clarification
Safer Solvents	Water-based extraction in juice clarification	Juice extraction
Energy Efficiency	Cogeneration using bagasse	Bagasse
Renewable Feedstocks	Use of sugarcane biomass	Bagasse, Molasses
Reduce Derivatives	Direct fermentation without chemical modification	Molasses
Catalysis	Use of enzymes in processing	Juice clarification
Design for Degradation	Biodegradable packaging from sugar derivatives	Bagasse derivatives
Real-time Analysis	Online effluent monitoring systems	Effluent
Inherently Safer Chemistry	Low-pressure steam systems for safety	Boiler operations

Table 1 shows how each principle translates into specific applications. For example, *atom economy* is realized when molasses is fermented directly into ethanol without unnecessary derivatization. *Energy efficiency* is achieved through cogeneration using bagasse, which reduces reliance on fossil fuels. *Design for degradation* is exemplified by biodegradable packaging derived from sugar-based polymers.

This mapping demonstrates that sugar chemistry is not isolated from sustainability concerns; rather, it is a fertile ground for applying green chemistry principles in real-world industrial contexts.

Case Study: Karnataka's Sugar Industry

Karnataka's sugar industry is deeply intertwined with rural livelihoods and regional economies. Yet, traditional processing methods generate significant environmental burdens. Effluents with high biological oxygen demand (BOD) pollute water bodies, boilers emit particulates and greenhouse gases, and residues such as press mud often accumulate without proper utilization.

Applying green chemistry principles offers pathways to mitigate these impacts.

- **Figure 1** (Bar chart) illustrates co-product utilization: Bagasse for cogeneration (~45%), Molasses for ethanol (~35%), and Press mud for compost (~20%). This demonstrates circular economy practices, where waste streams are vaporized into useful products.

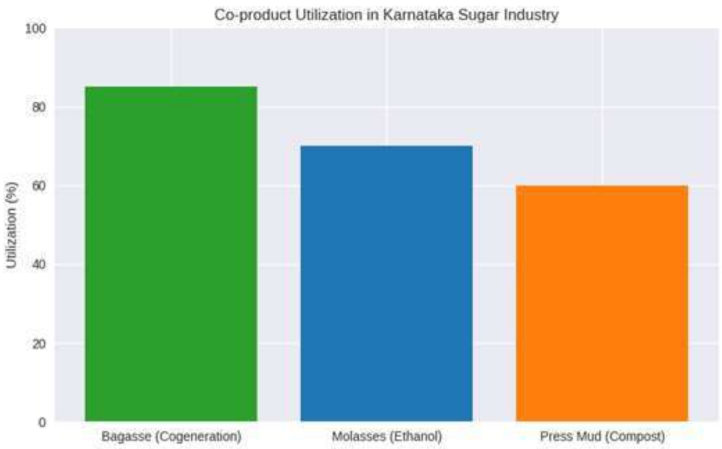

Figure 1 Illustrates co-product utilization

- **Bagasse utilization**: Instead of being discarded, bagasse is used for cogeneration of electricity. This reduces reliance on fossil fuels, embodies the principle of waste prevention, and contributes to energy efficiency. Cogeneration plants in Karnataka's mills often export surplus electricity to the grid, reinforcing the role of renewable feedstocks in industrial energy systems.
- **Molasses vaporization**: Molasses, a by-product of sugar crystallization, is converted into bioethanol. This process aligns with atom economy and renewable feedstock principles, while supporting India's ethanol blending program. Ethanol production not only diversifies revenue streams but also reduces dependence on petroleum-based fuels, contributing to national energy security.
- **Press mud composting**: Press mud, a solid residue from juice clarification, is composted into biofertilizer. This reduces dependence on synthetic fertilizers, improves soil health, and exemplifies the principle of designing safer

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chemicals. Farmers benefit from enhanced soil fertility and reduced input costs, linking industrial sustainability with agricultural resilience.

- **Effluent treatment**: Vinasse, the effluent from distilleries, is managed through real-time

Figure 2 (Line chart) shows ethanol production growth in Karnataka from 2015 to 2025, rising from ~400 million litres to ~950 million litres. This reflects the increasing role of molasses-based ethanol in India's energy mix, aligning with atom economy and renewable feedstock principles.

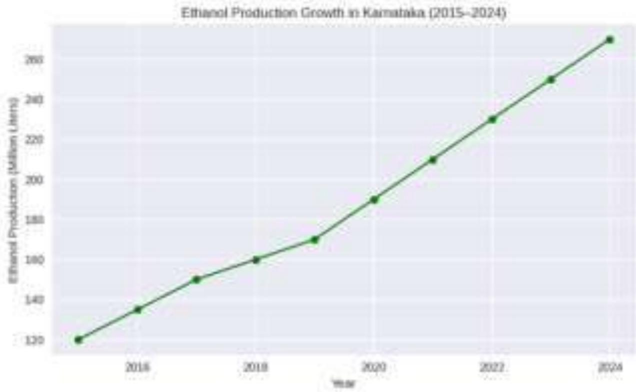

Figure 2 Ethanol production growth in Karnataka from 2015 to 2025

Figure 3 (Pie chart) depicts energy source distribution in sugar mills: bagasse cogeneration (60%), fossil fuels (30%), and other renewables (10%). This highlights the dominance of biomass-based energy, a clear example of energy efficiency and renewable feedstock use.

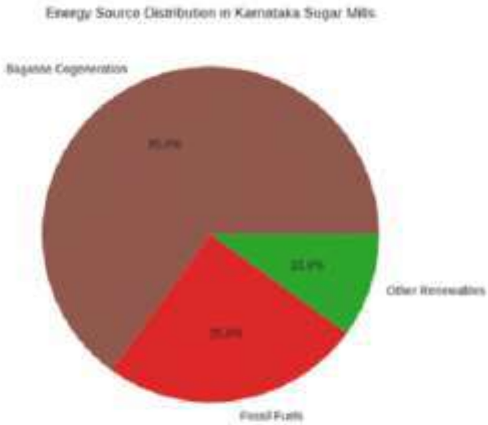

Figure 3 Depicts energy source distribution in sugar mills:

Together, these figures illustrate how Karnataka's sugar industry embodies green chemistry principles while contributing to sustainable energy and agricultural practices.

Sustainable Measures in Karnataka's Sugar Industry

Beyond process-level interventions, systemic sustainability measures are essential.

Table 2. Sustainable Measures in Karnataka's Sugar Industry

Sustainable Measure	Implementation in Karnataka Sugar Industry
Energy Efficiency	Cogeneration from bagasse, waste heat recovery
Water Stewardship	Closed-loop water systems, membrane filtration
Co-product Vaporization	Ethanol from molasses, compost from press mud
Catalysis and Biocatalysis	Enzymatic clarification, fermentation
Policy Integration	Ethanol blending mandates, compost subsidy

Table 2 outlines key sustainable measures:

- **Energy efficiency**: Cogeneration from bagasse and waste heat recovery reduce external electricity demand.
- **Water stewardship**: Closed-loop water systems and membrane filtration minimize freshwater use and effluent discharge.

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- **Co-product vaporization**: Ethanol from molasses and compost from press mud exemplify circular economy practices.
- **Catalysis and biocatalysis**: Enzymatic clarification and fermentation enhance selectivity and reduce toxic reagents.
- **Policy integration**: Ethanol blending mandates and compost subsidies align industry practices with national sustainability goals.

These measures show how green chemistry principles are embedded within broader sustainable chemistry frameworks, ensuring that industrial practices contribute to ecological and social well-being.

Challenges and Future Directions

Despite progress, several challenges remain. Scaling up green technologies requires significant capital investment, and infrastructural constraints hinder adoption in smaller mills. Seasonal variability in cane quality affects process consistency, while skills gaps limit effective operation of advanced technologies. Future research should focus on integrating Indian Knowledge Systems (IKS)**,** such as traditional fermentation and natural product chemistry, with modern biocatalysis to deepen contextual relevance. Life-cycle assessments of sugar-derived bioplastics and comparative studies across cooperative and private mills can provide further insights. Policy frameworks that incentivize sustainable practices and foster industry-academia collaboration will be crucial for scaling interventions.

Conclusion

The convergence of green chemistry, sustainable chemistry, and sugar chemistry illustrates how disciplinary boundaries can be transcended to achieve holistic outcomes. Green chemistry provides the principles for cleaner processes, sustainable chemistry situates these within societal goals, and sugar chemistry offers a tangible industrial case study. Karnataka's sugar industry demonstrates that chemistry, when practiced responsibly, can simultaneously advance economic growth, environmental protection, and social well-being. By vaporizing co-products, optimizing energy and water use, and embedding safety into process design, the sector can transition from being a source of environmental concern to a model of sustainable industrial practice. This case study reinforces the relevance of green chemistry in emerging economies, where industrial growth must be balanced with ecological stewardship and community well-being.

In short, green chemistry is not just about "clean chemistry" but about rethinking how we design, produce, and use chemicals to ensure they are safe, efficient, and sustainable.

References

1. Anastas, P., & Eghbali, N. (2010). *Green Chemistry: Principles and Practice*. RSC Publishing.
2. Anastas, P. T., & Warner, J. C. (1998). *Green chemistry: Theory and practice.* Oxford University Press.
3. Anastas, P. T., & Eghbali, N. (2010). Green chemistry: Principles and practice. *Chemical Society Reviews, 39*(1), 301–312. https://doi.org/10.1039/B918763B
4. Kurul, F., Doruk, B., & Topkaya, S. N. (2025). *Principles of green chemistry: Building a sustainable future.* Springer.
5. American Chemical Society. (n.d.). *Green chemistry case studies.* Retrieved December 17, 2025, from https://www.acs.org/green-chemistry-sustainability/education/case-studies.html
6. Bennett, E. (2024). Case studies in green chemistry: Successful industrial applications. *Purkh Journal of Chemistry, 11*(2). Retrieved December 17, 2025, from https://www.purkh.com/articles/case-studies-in-green-chemistry-successful-industrial-applications-109684.html
7. Solubility of Things. (2024). *Case studies in green chemistry applications.* Retrieved December 17, 2025, from https://www.solubilityofthings.com/case-studies-green-chemistry-applications
8. Gupta, V., Sharma, R., & Singh, A. (2020). Review on green chemistry approach. *International Journal of Creative Research Thoughts, 8*(5), 2320–2882.
9. Government of Karnataka. (2022–2024). *Annual reports on the sugar industry in Karnataka.* Department of Industries and Commerce.
10. Rao, P. S., & Singh, R. (2019). Sustainability in Indian sugar industry: Opportunities and challenges. *Journal of Cleaner Production, 230,* 1172–1181. https://doi.org/10.1016/j.jclepro.2019.05.123

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Original Article

Synthesis and Characterization of pH-Varied ZnONanofertilizers and Their Influence on Early Growth of Zea mays

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Abstract
The present study reports the synthesis, structural characterization, and agronomic evaluation of pH-varied zinc oxide nanoparticles (ZnO NPs) synthesized at pH 6, 8, 10, and 12, and their effect on seed germination and early growth performance of Zea mays. ZnO nanoparticles were prepared using the sol–gel method, while annealing temperature (400 °C) and duration (3 h) were maintained constant for all samples to ensure uniform thermal treatment. Structural and crystalline properties were analyzed using X-ray diffraction (XRD), confirming the formation of a hexagonal wurtzite crystal structure corresponding to standard JCPDS card No. 36–1451. The prominent diffraction peak associated with the (101) plane indicated well-crystallized, particle-like morphology of the synthesized ZnO nanoparticles. Agronomic evaluation revealed that ZnO nanoparticles synthesized at pH 10 exhibited superior performance compared to other treatments, showing the highest seed germination percentage (90%), shoot length (29.2 cm), root length (7.1 cm) and leaf area (25.6 cm²). The results demonstrate that pH plays a critical role in determining nanoparticle properties and their subsequent biological effectiveness, suggesting that optimally synthesized ZnO nanoparticles can serve as a promising nanonutrient for enhancing early growth in maize.

Keyword: *ZnO nanoparticles, Sol-Gel, Seed germination, Plant growth performance, Nanofertilizer.*

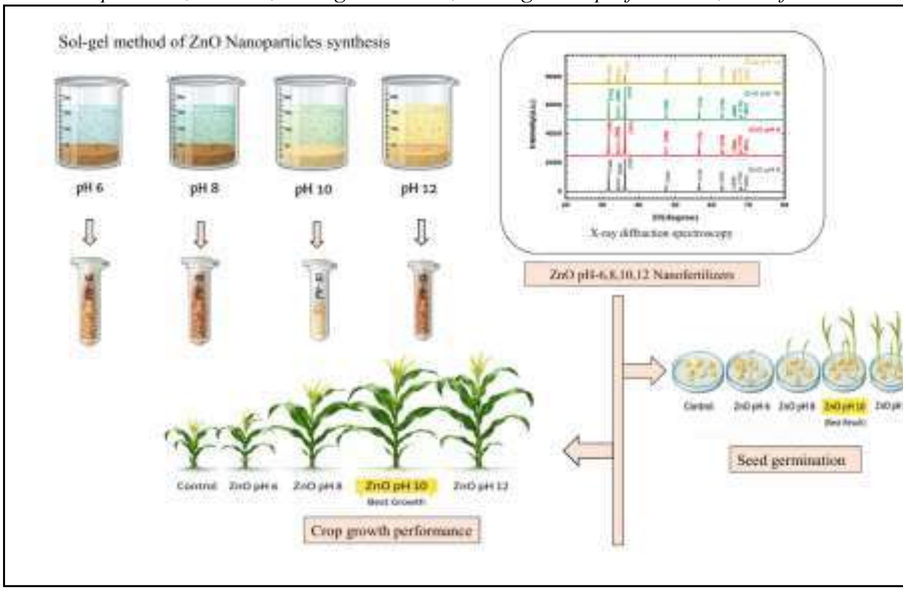

Fig.1. Graphical Abstract of Synthesis and Characterization of pH-Varied ZnONanofertilizers and Their Influence on Early Growth of *Zea mays*

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Introduction:

Agriculture remains a fundamental pillar of global food security and economic development, particularly in developing nations where crop productivity is closely linked to livelihood sustainability and nutritional well-being[1, 2]. However, increasing population pressure, progressive soil fertility depletion, and the excessive reliance on conventional chemical fertilizers have posed serious challenges to sustainable agricultural production systems[3]. Although traditional fertilizers have significantly contributed to yield enhancement, their limited nutrient-use efficiency, susceptibility to leaching losses, soil quality deterioration, and associated environmental pollution highlight the urgent need for innovative and sustainable nutrient management approaches[4].In this context, nanotechnology has gained considerable attention as an emerging strategy in modern agriculture due to its potential to enhance input efficiency while reducing environmental risks[5, 6]. Nanomaterials exhibit distinctive physicochemical characteristics, including large surface area-to-volume ratio, high reactivity, and controlled-release capabilities, which make them highly suitable for agricultural applications such as nutrient delivery, crop protection, and soil remediation[7-9]. The integration of nanotechnology into fertilizer formulations has facilitated the development of nanofertilizers that provide site-specific and sustained nutrient release, thereby improving nutrient uptake efficiency and minimizing losses compared to conventional fertilizer systems[10, 11]. Nanofertilizers are important in agriculture to increase crop yield and nutrient use efficiency and to reduce excessive use of chemical fertilizers[12]. Nanoparticles (NPs) are ranging from 1 to 100 nm.The key characteristics of nanofertilizers are that they contain one or more macronutrients and micronutrients can be applied in small quantity on frequent basis and are environmentally sustainable[13, 14]. Zinc oxide nanoparticles (ZnO NPs) have attracted considerable intrest in recent years because of their distinctive properties and potential application across various fields[15]. ZnOnanoparticles have been shown to have beneficial effects on plant growth and crop yield[15]. Zinc plays a crucial role in enzyme activities, hormone synthesis and DNA replication. However, Zn deficiency is a common problem in many soils, leading to reduced crop yields and poor nutritional quality[16]. ZnO NPs have been shown to enhance photosynthetic process by increased carbon assimilation and higher biomass accumulation.Effect of zinc nano-fertilizers on growth parameter of maize and wheat plant[17]. Nanotechnology has helped develop nano fertilizers, which are used in soil to improve its quality and help plants grow better[18, 19].The application of zinc oxide nanoparticles significantly enhanced the photosynthetic efficiency and strengthened the antioxidant defense system in tomato plants[20].

Maize is crucial cereal and versatile crop in poaceae family, used for human consumption animal and poultry feed and in various industrial application including the production of maize starch, dextrose, maize syrup and maize flakes[21, 22].

In the present research, we have synthesized pH variated ZnO nanoparticles by adopting sol gel method. This method offers better size of nanoparticles and the outcome shows the phase pure nanostructured zinc oxides powder. The physio-chemical characterization of pH variated ZnO NPs were studied using XRD technique. The effect of pH variated ZnO nanoparticles on the seed germination, shoot and root length and leaf area of *Zea mays* were studied.

Experimental Details:

(A) Material synthesis:

Zinc oxide (ZnO) nanofertilizer was synthesized using zinc sulphate as the precursor. The zinc sulphate solution was prepared in double-distilled water, and the pH of the solution was adjusted to 6, 8, 10, and 12 by the dropwise addition of ammonia solution (30%) as a complexing agent under continuous stirring. The resulting solution was heated on a hot plate with constant stirring until gel formation occurred. Heating was further continued until the gel was completely converted into a dry mass. The obtained dried mass was finely ground and subsequently annealed in a furnace at 800 °C for 4 h to obtain crystalline ZnO nanoparticles. The samples synthesized at different pH conditions were further subjected X ray diffraction spectroscopy.

(B) Agricultural application method:

(i) Seed germination method of maize treated with ZnO nanoparticles:

The synthesized pH-varied ZnO nanoparticles were used for the seed treatment of maize (*Zea mays* L.) Twenty healthy seeds were initially washed thoroughly with distilled water and subsequently surface sterilized using alcohol to avoid microbial contamination. The sterilized seeds were then treated with ZnO nanoparticle suspensions prepared at different pH conditions (6, 8, 10, and 12) for 24 h. Seeds pre-soaked in distilled water without nanoparticle treatment served as the control. After treatment, the seeds were allowed to germinate under controlled conditions, and the seed germination percentage was recorded on the seventh day of incubation.

(ii) Plant growth performance method of maize treated with ZnO nanoparticles:

Maize seeds (20 per treatment) were sown at a depth of approximately 2 cm in soil-filled pots under controlled growth conditions. Zinc oxide nanoparticles synthesized at different pH levels (6, 8, 10, and 12) were applied as a soil drench at a concentration of 10 ppm one week after seed germination. Untreated plants maintained under identical conditions served as the control. The effect of pH-varied ZnO nanoparticles on maize growth was evaluated twenty days after nanoparticle application by measuring germination percentage, shoot length, root length, root-to-shoot ratio,

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and leaf area. All experiments were conducted in triplicate, and the results were expressed as mean values of the respective treatments.

Result and Discussion:

(A) Characterization of Zinc nanoparticles by using XRD Technique:

Confirmation of material and to determine particle size Characterization of ZnO NPs was done by XRD i.e X-ray diffraction spectroscopy model AXS D8 Advance (Shivaji University Kolhapur). The diffraction pattern of ZnO NPs illustrates three distinct diffraction peaks located at angle of 31.76, 34.42, and 36.24°; and can be indexed with the planes (100), (002), and (101) of the hexagonal wurtzite type structure of the ZnO (JCPDS card No. 36–1451). The higher peak intensity of the diffraction peaks assigned to (101) plane suggests the particles-like nature of the prepared product[23]. Meanwhile, no other peaks were detected indicating a high purity level of the synthesized ZnO NPs. The average crystallite size of the NPs was determined by using following Debye–Scherrer formula.

$$D = \frac{K\lambda}{\beta cos\theta}$$

Where, D= crystallite size, λ = Wavelength of X ray, β= Full width half maxima (FWHM), θ = Angle of diffraction and k Scherrer constant = 0.98.

Table 1: Crystallite size of samples.

Sample	Crystallite size (D) nm
ZnO pH6	61.14nm
ZnO pH8	57.20nm
ZnO pH10	52.20nm
ZnO pH12	43.88nm

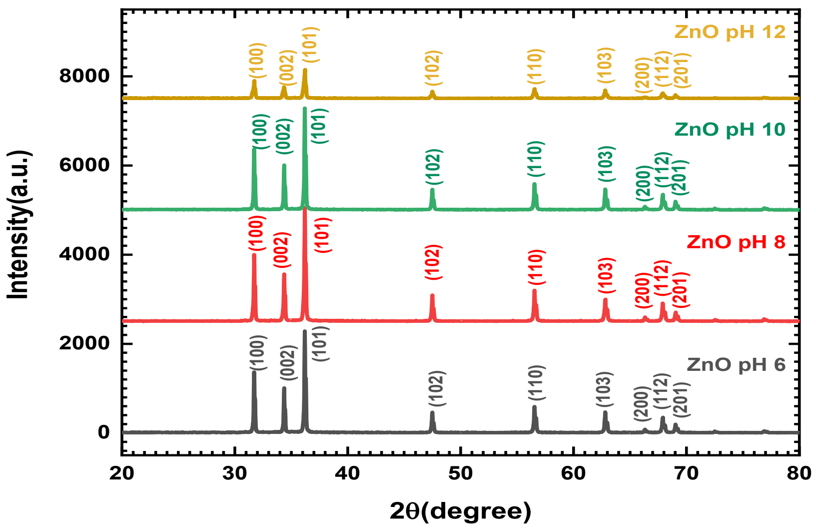

Fig.2.XRD of ZnO nanoparticle synthesized at pH 6, pH 8, pH 10 and pH 12.

(B) Seed germination of maize treated with ZnO nanoparticles:

The effect of pHvaried ZnO nanoparticles (ZnO NPs) on maize seed germination showed a clear influence of synthesis pH on germination performance. Seeds treated with ZnONPs synthesized at pH 6, 8, and 12 exhibited 80% germination, which was higher than the control (70%). The highest germination percentage (90%) was observed in seeds treated with ZnO NPs synthesized at pH 10, indicating that this condition produced nanoparticles with optimal properties for enhancing seed germination. Overall, ZnO NPs synthesized at alkaline pH, particularly pH 10, significantly improved maize seed germination compared to the untreated control. The application of zinc nanoparticles to enhance the germination rate in chili has been demonstrated to improve seed vigor and early seedling establishment by promoting enzymatic activity, nutrient availability, and metabolic processes during germination[24]. Zinc oxide nanoparticles significantly enhance the seed germination rate of Camelina sativa and Brassica napus by improving nutrient availability and stimulating early metabolic activity, though higher concentrations may inhibit growth[25]. Zinc oxide nanoparticles were found to increase seed germination and vigor in maize seeds by enhancing nutrient uptake, activating germination-related enzymes, and promoting early seedling growth[26].

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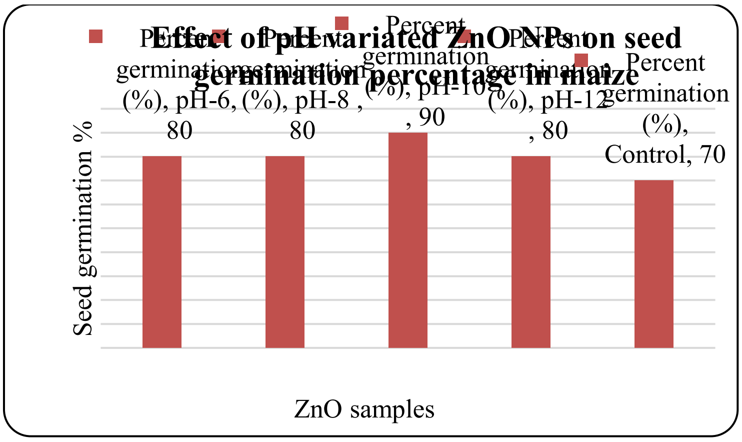

Fig.3. Effect of pH variated ZnO nanoparticles on percent seed germination in maize.

(C) Plant growth performance of maize treated with ZnO nanoparticles:

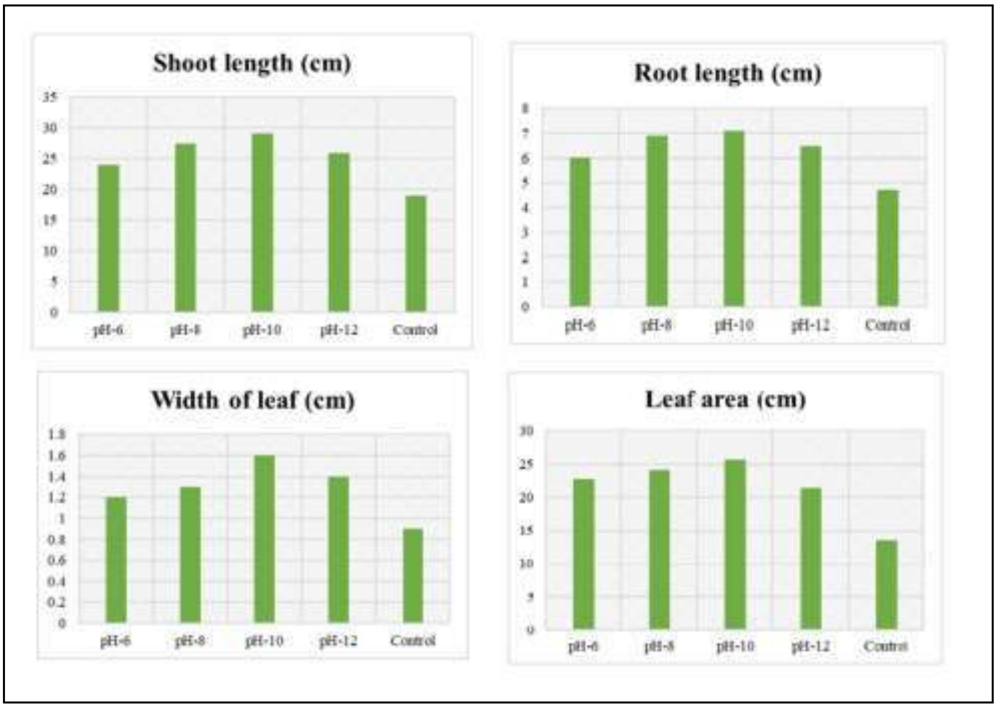

Fig.4. Effect of pH variated ZnO nanoparticles on different parameter in maize.

The growth performance of maize seedlings was markedly influenced by the application of pH-varied ZnO nanoparticles. Among all treatments, ZnO nanoparticles synthesized at pH 10 showed the highest enhancement in vegetative growth parameters. The maximum shoot length (29 cm) was recorded at pH 10, followed by pH 8 (27 cm), pH 12 (25 cm), and pH 6 (24 cm), whereas the control exhibited the lowest shoot length (19 cm). A similar trend was observed in root development, where root length increased from 6.0 cm at pH 6 to 7.2 cm at pH 10, compared to 4.8 cm in the control.

Leaf growth parameters also showed significant improvement with ZnO nanoparticle treatments. The maximum leaf width (1.6 cm) and leaf area (25.8 cm) were observed at pH 10, followed by pH 8 and pH 12 treatments, while the control recorded the lowest values (0.9 cm leaf width and 14 cm leaf area). The enhanced shoot and root growth, along with increased leaf dimensions, indicate improved nutrient uptake, better photosynthetic surface development, and enhanced metabolic activity in ZnO NPtreated plants. Overall, ZnO nanoparticles synthesized at pH 10 demonstrated superior effectiveness in improving maize crop growth performance compared to other pH treatments and the control.Results of the application of zinc nanoparticles on maize traits have been reported to boost both plant growth and yield by enhancing nutrient uptake, chlorophyll synthesis, enzymatic activity, and overall physiological performance[27]. Zinc oxide nanoparticles have emerged as promising seed priming agents in plant growth applications, showing positive effects on both plant development and yield[28]. Zinc oxide nanofertilizers enhance plant growth and yield in maize crop according to several studies, primarily through improved zinc availability, enhanced photosynthetic efficiency, and stimulation of metabolic and enzymatic activities involved in plant growth[29].

Conclusion:

The present study demonstrates that the synthesis pH plays a crucial role in determining the structural characteristics and agronomic performance of zinc oxide nanoparticles. ZnO nanoparticles synthesized via the sol–gel method and annealed at 400 °C for 3 h exhibited a well-defined hexagonal wurtzite crystal structure, confirming successful formation of crystalline nanoparticles. Agronomic evaluation revealed that ZnO nanoparticles synthesized at pH 10 significantly enhanced seed germination and early growth performance of *Zea mays*, as evidenced by higher germination percentage, shoot and root length, root-to-shoot ratio, and leaf area compared to other treatments and the control.

The improved growth response may be attributed to optimized nanoparticle properties that enhanced zinc availability and stimulated physiological and metabolic activities during early plant development. Overall, the findings indicate that pH-optimized ZnO nanoparticles can serve as an effective nanonutrient for improving early crop establishment in maize. Further studies under field conditions are recommended to assess their long-term agronomic efficiency and practical applicability in sustainable agriculture.

Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. The authors declare the following financial interests/personal relationships which may be considered as potential competing interests

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Funding Declaration

No Funding

Conflict of interest

There is no conflict of interest involved in the study.

Ethics declaration: not applicable.

Author Contribution declaration

Miss Dipali R. Ingavale- Methodology, Writing-original draft, Formal analysis, Data curation.

Dr. Panditrao D. Shiragave-Formal analysis, Visualization, Investigation, Conceptualization

References:

1. Sharma, D.s (2024) Harmonizing Sustainable Agriculture For Enhanced Food Security, Nutrition And Poverty Alleviation, Poverty Interdisciplinary Perspectives on Sustainable Development from Vision to Action
2. Welch, R.M. and R.D. Grahams (1999) A new paradigm for world agriculture: meeting human needs: productive, sustainable, nutritious Field crops research 60:1-10
3. Gruhn, P., F. Goletti, and M. Yudelman (2000) Integrated nutrient management, soil fertility, and sustainable agriculture: current issues and future challenges
4. Nakachew, K., H. Yigermal, F. Assefa, Y. Gelaye, and S. Alis (2024) Review on enhancing the efficiency of fertilizer utilization: Strategies for optimal nutrient management Open Agriculture 9:20220356
5. Yadav, A., K. Yadav, R. Ahmad, and K.A. Abd-Elsalams (2023) Emerging frontiers in nanotechnology for precision agriculture: advancements, hurdles and prospects Agrochemicals 2:220-256
6. Prasad, R., A. Bhattacharyya, and Q.D. Nguyens (2017) Nanotechnology in sustainable agriculture: recent developments, challenges, and perspectives Frontiers in microbiology 8:1014
7. Yadav, A., K. Yadav, and K.A. Abd-Elsalams (2023) Nanofertilizers: types, delivery and advantages in agricultural sustainability Agrochemicals 2:296-336
8. Dwivedi, S., Q. Saquib, A.A. Al-Khedhairy, and J. Musarrat (2016) Understanding the role of nanomaterials in agriculture Microbial Inoculants in Sustainable Agricultural Productivity: Vol. 2: Functional Applications 271-288
9. Sales, H.B., A. de S. Carolino, R.Z. de A. Nunes, C.M. Macalia, C.M. Ruzo, C. da C. Pinto, J. de A. Bezerra, P.H. Campelo, Ș. Țălu, and L.K. de Souzas (2024) Advances in agricultural technology: A review of slow-release nanofertilizers and innovative carriers Communications in soil science and plant analysis 55:1849-1882
10. Singh, M., S.P. Goswami, P. Sachan, D.K. Sahu, S. Beese, and S.K. Pandeys (2024) Nanotech for fertilizers and nutrients-improving nutrient use efficiency with nano-enabled fertilizers Journal of Experimental Agriculture International 46:220-247

Journal of Research and Development
A Multidisciplinary International Level Referred and Double-Blind Peer Reviewed, Open Access
ISSN : 2230-9578 | Website: https://jrdrvb.org Volume-18, Issue-2(VI)| February- 2026

11. Munir, A., M.A. Salah, M. Ali, B. Ali, M.H. Saleem, K. Samarasinghe, S. De Silva, S. Ercisli, N. Iqbal, and M. Anass (2024) Advancing agriculture: harnessing smart nanoparticles for precision fertilization BioNanoScience 14:3846-3863
12. Singh, M.D.s (2017) Nano-fertilizers is a new way to increase nutrients use efficiency in crop production International Journal of Agriculture Sciences, ISSN 9:0975-3710
13. Fatima, F., A. Hashim, and S. Aneess (2021) Efficacy of nanoparticles as nanofertilizer production: a review Environmental Science and Pollution Research 28:1292-1303
14. Semenova, N.A., D.E. Burmistrov, S.A. Shumeyko, and S.V. Gudkovs (2024) Fertilizers based on nanoparticles as sources of macro-and microelements for plant crop growth: A review Agronomy 14:1646
15. Islam, F., S. Shohag, M.J. Uddin, M.R. Islam, M.H. Nafady, A. Akter, S. Mitra, A. Roy, T.B. Emran, and S. Cavalus (2022) Exploring the journey of zinc oxide nanoparticles (ZnO-NPs) toward biomedical applications Materials 15:2160
16. Suganya, A., A. Saravanan, and N. Manivannans (2020) Role of zinc nutrition for increasing zinc availability, uptake, yield, and quality of maize (*Zea mays* L.) grains: An overview Commun. Soil Sci. Plant Anal 51:2001-2021
17. Azam, M., H.N. Bhatti, A. Khan, L. Zafar, and M. Iqbals (2022) Zinc oxide nano-fertilizer application (foliar and soil) effect on the growth, photosynthetic pigments and antioxidant system of maize cultivar Biocatalysis and Agricultural Biotechnology 42:102343
18. Al-Juthery, H.W., N.R. Lahmod, and R.A. Al-Taee (2021) Intelligent, nano-fertilizers: A new technology for improvement nutrient use efficiency (article review) IOP conference series: Earth and environmental science 735:012086
19. Shang, Y., M.K. Hasan, G.J. Ahammed, M. Li, H. Yin, and J. Zhous (2019) Applications of nanotechnology in plant growth and crop protection: a review Molecules 24:2558
20. Faizan, M., A. Faraz, M. Yusuf, S. Khan, and S. Hayats (2018) Zinc oxide nanoparticle-mediated changes in photosynthetic efficiency and antioxidant system of tomato plants Photosynthetica 56:678-686
21. Amanjyoti, J. Singh, D. Sowdhanya, P. Rasane, J. Singh, S. Ercisli, H. Verma, and R. Ullah (2024) Maize Cereals and nutraceuticals 47-80
22. Malhotra, S.K. (2017) Diversification in utilization of maize and production Proceedings of Gyan Manthan Conference: Perspective of Maize Production and Value Chain. A Compendium 5:49-57
23. Zhu, Y. and Y. Zhous (2008) Preparation of pure ZnO nanoparticles by a simple solid-state reaction method Applied Physics A 92:275-278
24. Hasan, N., N.F. Amran, N. Ahmad, S.N. Maadon, N.H. Saat, and M.R. Yusof (2025) Zinc oxide nano-priming for germination performance of chili (Capsicum annuum L.) AIP Conference Proceedings 3275:040007
25. Sarkhosh, S., D. Kahrizi, E. Darvishi, M. Tourang, S. Haghighi-Mood, P. Vahedi, and S. Ercislis (2022) Effect of zinc oxide nanoparticles (ZnO-NPs) on seed germination characteristics in two Brassicaceae family species: Camelina sativa and Brassica napus L Journal of Nanomaterials 2022:1892759
26. Kumar, S.M., S. Yadav, R. Choudhary, A. Anumantharaj, A. Yadav, Z. Hussain, P.K. Singh, S.P. Singh, A. Mandal, and N. Singhs (2025) Nanopriming with zinc oxide nanoparticle boosts seed vigour, photosynthesis, osmolytes accumulation and antioxidant activity in tomato Scientific Reports 15:37375
27. Seleiman, M.F., A. Ahmad, B.A. Alhammad, and E. Tolas (2023) Exogenous application of zinc oxide nanoparticles improved antioxidants, photosynthetic, and yield traits in salt-stressed maize Agronomy 13:2645
28. Donia, D.T. and M. Carbones (2023) Seed priming with zinc oxide nanoparticles to enhance crop tolerance to environmental stresses International Journal of Molecular Sciences 24:17612
29. Prakash, V., P. Rai, N.C. Sharma, V.P. Singh, D.K. Tripathi, S. Sharma, and S. Sahis (2022) Application of zinc oxide nanoparticles as fertilizer boosts growth in rice plant and alleviates chromium stress by regulating genes involved in oxidative stress Chemosphere 303:134554

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Original Article

Analysis Of Pesticide Content in Vegetables and Fruits Collected from Gadag District

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Abstract

The rapid intensification of agricultural practices has led to the increased release of toxic organic and inorganic compounds into the environment. Due to their extensive application, persistence, selective toxicity, and tendency to bioaccumulate, pesticides are among the most hazardous environmental contaminants. Fruits and vegetables are particularly vulnerable to contamination, making them a major route of human exposure. Therefore, systematic monitoring of pesticide residues in these food commodities using reliable analytical techniques is essential.

This review, entitled "Analysis of Pesticide Content in Vegetables and Fruits Collected from Gadag district", compiles findings from the literature concerning the Maximum Residue Levels (MRLs) of selected pesticides detected in fruit and vegetable samples. It also examines the occurrence of pesticide and insecticide residues in these food items. The consumption of contaminated produce can lead to significant health problems in humans. Short-term effects include asthma, throat irritation, skin and eye irritation, and diarrhea, whereas long-term exposure has been associated with cancer, neurological disorders, reproductive complications, diabetes, and other chronic conditions. The objective of this review is to summarize the concentrations of commonly used pesticides found in fruits and vegetables and to highlight their potential impacts on human health.

Introduction:

Over the past decade, agricultural productivity has increased markedly to meet the demands of a rapidly growing population. This rise in crop yield has largely been achieved through the extensive application of pesticides and insecticides—chemicals sprayed on crops to protect them from pests [1, 2]. Common examples include DDT, BHC, zinc phosphide, mercuric chloride, and dinitrophenol. Since all pesticides are inherently toxic, they must be used cautiously and in limited amounts.

Pesticides are effective against a wide range of insects, weeds, and fungi, and are therefore classified as insecticides, herbicides, and fungicides, respectively. However, many of them are non-biodegradable and persist in the environment, accumulating in plants, fruits, and vegetables. These residues enter the food chain when contaminated produce is consumed by animals, birds, and humans. Once inside the body, they tend to bioaccumulate and may cause serious health problems [3, 4]. In recent years, preference has shifted toward biodegradable insecticides such as malathion. Nevertheless, the detection of insecticide residues in raw food items such as wheat, fish, meat, and butter has raised global concern among agricultural authorities, scientists, and health officials, highlighting the need for stricter regulation and alternative, non-chemical pest control strategies.

Pesticides are highly hazardous and potentially lethal to both wildlife and humans. They pose risks not only to consumers but also to workers and bystanders during manufacture, transportation, application, and even after use. Residues may remain in food crops despite washing or peeling. Additionally, pesticides reduce soil biodiversity, and studies indicate that soil quality and water retention capacity are often higher in the absence of pesticide use. Many pesticides are extremely toxic; even small quantities can be fatal to humans and animals.

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Prolonged or repeated exposure may lead to chronic illnesses. Research indicates a significant increase—up to 70%—in the risk of developing Parkinson's disease among individuals exposed to low levels of pesticides. Long-term health effects associated with pesticide exposure include respiratory disorders, memory impairment, skin diseases, cancer, depression, neurological damage, miscarriages, and birth defects. Acute effects may involve eye irritation, skin rashes, blisters, nausea, dizziness, diarrhea, and even death, whereas chronic effects include infertility, developmental toxicity, immunotoxicity, and endocrine disruption.

Children are particularly vulnerable to pesticide exposure, with diet being the primary source of contamination in infants and young individuals. Early-life exposure has been linked to brain cancer, leukemia, and congenital abnormalities. Studies suggest that children consuming organic diets have lower exposure to harmful organophosphorus pesticides. Consequently, organophosphorus pesticides are increasingly used because they are generally less persistent and comparatively less environmentally damaging than organochlorine pesticides.


Effects on environment

Pesticides offer several benefits in agricultural production; however, they also cause significant environmental damage. Considering both their advantages and adverse impacts, efforts should be directed toward achieving greater selectivity in their action so that only target organisms are affected. Despite such intentions, recent studies indicate that pesticides continue to pose serious risks to environmental safety and human health.

Pesticides have the potential to contaminate soil, water bodies, lawns, and surrounding vegetation. While they are designed to eliminate insects and weeds, they may also harm non-target organisms such as birds, fish, beneficial insects, and other plants. Among the different categories, insecticides are generally the most acutely toxic, although herbicides can likewise threaten non-target species.

Pesticides may enter surface water through runoff from treated fields and soils, leading to widespread water contamination. Groundwater pollution resulting from pesticide use has become a global concern. Moreover, numerous transformation products (TPs) derived from various pesticides have been identified. However, only a limited number of these potential transformation products have been systematically monitored in soils, highlighting the urgent need for further research in this area.

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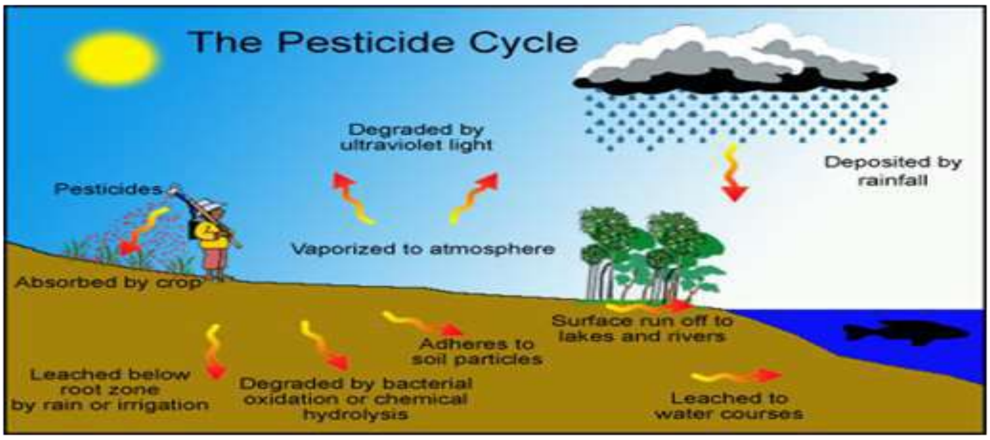

Types Of Pesticides Used in Fruits and Vegetables

In the study areas, most farmers had only primary-level education and lacked formal training in pesticide use. The majority reported relying on synthetic pesticide formulations for crop protection against a variety of pests and insects. These products were generally identified by their trade names, and farmers were often unaware of their chemical composition or mode of action. Among the different categories, insecticides were used most frequently, followed by fungicides and herbicides. Some of the pesticides in use are classified as extremely or highly hazardous by the World Health Organization.

Commonly applied insecticides included chlorpyrifos, monocrotophos, cypermethrin, and quinalphos. Frequently used fungicides were copper oxychloride, carbendazim (marketed as Bavistin), and mancozeb. Herbicides commonly used included glyphosate and paraquat [5, 6].

The survey revealed that multiple pesticide formulations were often applied to a single crop during different stages of cultivation. Farmers reported obtaining pesticides from various sources, with agrochemical shops in local and municipal markets serving as the primary suppliers. Storage practices were generally unsafe and casual; pesticides were frequently kept outside houses alongside fertilizers and farm equipment, and in some cases, stored inside residential areas [7, 8].

Information regarding pesticide use was mainly acquired through television advertisements, radio broadcasts, leaflets and pamphlets distributed by agrochemical retailers, as well as guidance from government agricultural officers and sales representatives of agrochemical companies.

Materials And Chemicals Required

Mortar and pestle, beakers, funnel, glass rod, filter paper china dish, water bath, tripod stand, fusion tube, knife, test tube. Samples of various fruits and vegetables, alcohol, sodium metal, ferric chloride, ferrous sulphate crystals, distilled water and dil. Sulphuric acid.

Procedure

Take different types of fruits and vegetables and cut them into small pieces separately. Transfer the cut pieces of various fruits and vegetables into it separately and crush them. Take different kinds for each kind of fruits and vegetables and place the crushed fruits and vegetables in these beakers and add 100 ml of alcohol to each of these. Stir well and filter. Collect the filtrate in separate china dishes, Evaporate the alcohol by heating the china dishes one by one over a water bath and let the residue dry in the oven. Heat a small piece of sodium in a fusion tube, till it melts. Then add one of the above residues from the china dish to this fusion tube and heat it till red hot. Drop the hot fusion tube in a china dish containing about 10 ml of distilled water. Break the tube and boil the contents of the china dish for about 5 minutes. Cool and filter the solution. Collect the filtrate. To the filtrate add 1 ml of freshly prepared ferrous sulphate solution and warm the contents. Then add 2-3 drops of ferric chloride solution and acidify with dilute HCl. If a blue or green ppt. or coloration is obtained it indicates the presence of nitrogen containing insecticides. To the filtrate add 3-4 drops of fresh and very dilute sodium nitroprusside solution and 1-2 drops of NaOH solution. If intense purple colour it indicates the presence of sulphur containing pesticides. To the filtrate add dil HNO_3 till acidic boil well, cool and few drops of silver nitrate ($AgNO_3$) solution. If precipitation is obtained then it indicates halogen containing pesticides present in the sample. Repeat the test of nitrogen, sulphure and halogen for residues obtained from other fruits and vegetables and record the observation.

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Observation

SL. No.	Vegetables & Fruits	Nitrogen	Sulphure	Halogen
	Brinjal	Yes		
	Ladies finger	Yes		
	Cucumber	Yes		Yes
	Banana			Yes
	Chilli			Yes
	Apple	Yes		Yes
	Orange	Yes		Yes
	Cucumber	Yes		Yes
	Garlic	Yes		Yes
	Banana			Yes
	Beetroot	Yes		Yes
	Cauliflower	Yes		Yes
	Cucumber	Yes		Yes
	Tomato	Yes		
	Potato	Yes	Yes	Yes
	Tomato	Yes		

Result And Discussions

The detection of pesticide residues in both primary and processed agricultural products poses significant health risks to consumers. This study aimed to evaluate the levels of pesticide residues in commonly consumed fruits and vegetables in Gadag. A total of sixteen fresh fruit and vegetable samples were analyzed using elemental analysis to determine the presence of pesticide residues.

The findings revealed that 25% of the samples contained nitrogen, 18.75% showed the presence of halogens, and 56% contained both nitrogen and halogens, indicating possible pesticide contamination. These results confirm the occurrence of pesticide residues in widely consumed produce in Gadag and highlight the urgent need for comprehensive intervention strategies to minimize potential health risks to consumers.

Regular monitoring of pesticide residues is strongly recommended, along with increased awareness and training for farmers on safe pesticide practices, particularly adherence to the prescribed pre-harvest intervals.

Effects of Pesticides on Humans

Pesticides are chemical substances used to control pests such as insects, weeds, fungi, and rodents. While they help increase agricultural productivity, improper use and exposure can cause harmful effects on human health. Organochlorine pesticides (DDT, chlordane, and heptachlor) affect mammary cells by producing oestrogen, which enhances the probability of breast cancer [9, 10]. The metabolites of organochlorine pesticides increase the number of type 2 diabetes and other associated complications [11, 12]. Miranda et al. [12] also reported that a higher concentration of DDT and/or heptachlor epoxide in blood enhances the probability of diabetic neuropathy. Allergies like itching, sneezing, irritation of the nose, watery eyes, and skin irritation (blisters, rash, and rhinitis) are also caused by pesticides [13]. Leukaemia and non-Hodgkin's lymphoma development in humans are linked with pesticide, particularly organophosphate pesticide exposure [14-17].

Conclusions

This study examined the levels of pesticide residues in commonly consumed fruits and vegetables in Gadag. The findings revealed that a majority of the analyzed samples were contaminated with detectable pesticide residues. From a public health standpoint, the presence of these residues may pose potential health risks to consumers.

To mitigate such risks, it is essential to promote greater awareness among farmers regarding safe pesticide handling and application practices. In addition, continuous monitoring and systematic surveillance of pesticide residues in agricultural produce are strongly recommended to ensure food safety and protect public health.

References

1. Alokail, M. S., Elhalwagy, M. E., Abd-Alrahman, S. H., et al. (2024). Pesticide residues and associated health effects in marketed fruits in Saudi Arabia. Arabian Journal of Chemistry, 17(11), 105993. DOI: 10.1016/ j. arabjc.2024.105993
2. Qin, G., Chen, Y., He, F., et al. (2020). Risk assessment of fungicide pesticide residues in vegetables and fruits in the midwestern region of China. Journal of Food Composition and Analysis, 95, 103663. DOI; 10.1016/j.jfca.2020.103663
3. van den Berg, H., Bezerra, S., Chanda, E., et al. (2021). Management of insecticides for use in disease vector control: A global survey. BMC Infectious Diseases, 21, 468. DOI: 10.1186/s12879-021-06155-y.

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A Multidisciplinary International Level Referred and Double-Blind Peer Reviewed, Open Access
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4. Meier, C. J., Rouhier, M. F. and Hillyer, J. F. (2022). Chemical Control of Mosquitoes and the Pesticide Treadmill: A Case for Photosensitive Insecticides as Larvicides. Insects, 13(12), 1093. DOI: 10.3390/ insects13121093
5. Elmastas, A., Umaz, A., Pirinc, V., et al. (2023). Quantitative determination and removal of pesticide residues in fresh vegetables and fruit products by LC–MS/MS and GC–MS/MS. Environmental Monitoring and Assessment, 195 (2), 277- 308.
6. Osaili, T.M., Al Sallagi, M.S., Dhanasekaran, D.K. et al. (2022). Pesticide residues in fresh vegetables imported into the United Arab Emirates. Food Control, 133, 108663-108674.
7. Osaili, T. M., Al Sallagi, M. S., Dhanasekaran, D. K., et al. (2022a). Pesticide residues in fresh fruits imported into the United Arab Emirates. Heliyon, 8(12), e11946–e11961.
8. Kapeleka, J. A., Sauli, E., Sadik, O., et al. (2020). Co-exposure risks of pesticides residues and bacterial contamination in fresh fruits and vegetables under smallholder horticultural production systems in Tanzania. PLoS One 15, e0235345– e0235323. DOI: 10.1371/journal.pone.0235345
9. Rebouillat, P., Vidal, R., Cravedi, J.P., et al. (2021). Prospective association between dietary pesticide exposure profiles and postmenopausal breast-cancer risk in the NutriNet-Santé cohort. Int J Epidemiology, 50,184-1198
10. Franke, A.A., Li, X., Shvetsov, Y.B., et al. (2021). Pilot study on the urinary excretion of the glyphosate metabolite aminomethylphosphonic acid and breast cancer risk: the multiethnic cohort study. Environmental Pollution, 277:116848.
11. Kumar, V., Sharma, N., Sharma, P., et al. (2023). Toxicity analysis of endocrine disrupting pesticides on non-target organisms: A critical analysis on toxicity mechanisms. Toxicology and Applied Pharmacology, 474, 116623. DOI: 10.1016/j.taap.2023.116623.
12. Miranda, R.A., Silva, B.S., de Moura, E.G., et al. (2023). Pesticides as endocrine disruptors: programming for obesity and diabetes (Review). Endocrine, 79, 437-447.
13. Juntarawijit, Y. and Juntarawijit C. (2023). Pesticide exposure and rhinitis: A cross-sectional study among farmers in Pitsanulok, Thailand. F1000Research, 10:474. DOI: 10.12688/f1000research.53257.3.
14. Latifovic, L., Freeman, L.E.B., Spinelli, J.J., et al. (2020). Pesticide use and risk of Hodgkin lymphoma: results from the North American pooled project (NAPP). Cancer Causes Control, 31,583-599.
15. Rafeeinia, A., Asadikaram, G., Moazed, V., et al. (2023). Organochlorine pesticides may induce leukemia by methylation of CDKN2B and MGMT promoters and histone modifications. Gene, 851, 146976. DOI: 10.1016/j.gene.2022.146976
16. De Roos, A.J., Schinasi, L.H., Miligi, L., et al. (2021). Occupational insecticide exposure and risk of non-Hodgkin lymphoma: a pooled case-control study from the Inter Lymph consortium. International Journal of Cancer, 149, 1768- 1786.
17. Weisenburger, D. D. (2021). A Review and Update with Perspective of Evidence that the Herbicide Glyphosate (Roundup) is a Cause of Non-Hodgkin Lymphoma. Clinical Lymphoma Myeloma and Leukemia, 21(9), 621-630. DOI: 10.1016/j.clml.2021.04.009.

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Original Article

Floristic Diversity of Nipani and Surrounding Area of Belgaum district, Karnataka

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Abstract

This study investigates the floral diversity in the region of Nipani and its surrounding areas, located in the Belgaum district of Karnataka, India. The area, which lies at the intersection of the Western Ghats and the Konkan region, is known for its rich biodiversity, influenced by its unique geographical and climatic features. Field surveys were conducted to document and identify plant species, focusing on their botanical names, family associations, and common names. A total of X plant species from Y different families were documented, providing an overview of the region's botanical richness.

Keywords: *Flora, Biodiversity, Nipani, Belgaum, Karnataka, Plant species, Western Ghats, Konkan region.*

Introduction:

Biodiversity describes the richness and variety of life on earth. It is the most complex and important feature of our planet. Without biodiversity, life would not sustain. The term biodiversity was coined in 1985. It is important in natural as well as artificial ecosystems. It deals with nature's variety, the biosphere. It refers to variability among plants, animals and microorganism species. Biodiversity includes the number of different organisms and their relative frequencies in an ecosystem. It also reflects the organization of organisms at different levels.

Biodiversity holds ecological and economic significance. It provides us with nourishment, housing, fuel, clothing and several other resources. It also extracts monetary benefits through tourism. Therefore, it is very important to have a good knowledge of biodiversity for a sustainable livelihood.

Biological diversity refers to the diversity of life in all its forms and at all levels of organization. According to the Convention on Biological Diversity (CBD) of 1992, biological diversity means the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part. This includes diversity within species, between species and of ecosystems. Biologist E.O. Wilson has a more detailed definition (Wilson 1988): 'The variety of life at every hierarchical level and spatial scale of biological organizations: genes within populations, populations within species, species within communities, communities within landscapes, landscapes within biomes, and biomes within the biosphere

Nipani, a significant town in the Belgaum district, Karnataka, is geographically located near the Western Ghats, known for its rich biodiversity. The biodiversity of this region is underexplored, especially in terms of its floral species. This paper aims to document and analyze the various plant species found in Nipani and its surrounding areas. The study will help in understanding the diversity and ecological significance of the region, contributing to conservation and sustainable management efforts.

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Material and Methods

Study Area

Nipani lies in the southwestern part of Karnataka, adjacent to the Western Ghats and the Konkan region. The climate is tropical, with a substantial monsoon season that supports a diverse range of plant species. The area is primarily an agricultural and commercial hub. Field surveys were conducted over a period of six months to collect data on plant species. Photographs and specimens were collected, and identification was done based on standard botanical references.

Results and Discussion

During the study, several species from different families were documented. Below is a summary of some of the key species found in the area.

Sr. No.	Scientific Name	Family	Common Name	Photos
1	**Alysicarpus pubescens**	Fabaceae	Bicolor Alyce Clover	
2	**Asclepias curassavica**	Apocynaceae	Scarlet Milkweed	
3	**Cardiospermum halicacabum**	Sapindaceae	Balloon Vine	
4	**Celosia argentea**	Amaranthaceae	White Cockscomb, Flamingo Feathers	
5	**Ceropegiahirsuta**	Apocynaceae	Hairy Ceropegia	

6	**Cleome viscosa**	Cleomaceae	Asian spider flower	
7	**Commelina benghalensis**	Commelinaceae	Bengal Dayflower	
8	**Cosmos sulphureus**	Asteraceae	Sulphur Cosmos	
9	**Cyanotisfasciculata**	*Commelinaceae*	Fascicled-Flower Dew-Grass	
10	**Cyanotistuberosa**	Commelinaceae	Sahyadri Dew-Grass	
11	**Evolvulusalsinoides**	Convolvulaceae	Vishnukranti	

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12	**Habenariagrandifloriformis**	Orchidaceae	SingleLeavedH abenaria	
13	**Hibiscus lobatus**	Malvaceae	Lobed Leaf Mallow	
14	**Hygrophilaauriculata**	Acanthaceae	Talimkhana	
15	**Impatiens balsamia**	Balsaminaceae	Garden Balsam	
16	**Iphigenia indica**	Colchicaceae	Bhuichakra	

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17	**Ipomoea parasitica**	Convolvulaceae	Yellow-Throated Morning Glory	
18	**Lagasceamollis**	Asteraceae	American softhead	
19	**Lantana camara**	Verbenaceae	Lantana	
20	**Lavandulabipinnata**	Lamiaceae	Feather-leaved Lavender	
21	**Leonotisnepetifolia**	Lamiaceae	Christmas candlestick	
22	**Leucaslongifolia**	Lamiaceae	Long-Leaf Leucas	

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23	**Martyniaannua**	Martyniaceae	Devil's Claw	
24	**Mesosphaerumsuaveolens**	Lamiaceae	American Mint,	
25	**Mimosa pudica**	Mimosaceae	Sensitive Plant, Touch-me-not	
26	**Morinda citrifolia**	Rubiaceae	Indian Mulberry	
27	**Muntingia calabura**	**Muntingiaceae**	Singapori Cherry	
28	**Neolamarckia cadamba**	Rubiaceae	Kadamba	

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29	**Nicandra physaloides**	Solanaceae	Shoofly Plant	
30	**Oxalis debilis**	**Oxalidaceae**	pink-sorrel or pink woodsorrel	
31	**Oxalis stricta**	**Oxalidaceae**	sleeping beauty	
32	**Parasopubiadelphinifolia**	Orobanchaceae	Common Sopubia	
33	**Peltophorumpterocarpum**	**Fabaceae**	Yellow flametree	

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34	**Plumbagozeylanica**	Plumbaginaceae	White Leadwort	
35	**Rothecaserrata**	Verbenaceae	Blue Fountain Bush	
36	**Strigadensiflora**	Orobanchaceae	Dense flower Witch weed	
37	**Terminalia arjuna**	Combretaceae	Arjun	
38	**Tithonia rotundifolia**	Asteraceae	Mexican Sunflower	

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39	**Tridax procumbens**	Asteraceae	coatbuttons	

Discussion

The flora in Nipani reflects a mix of tropical and subtropical species, with several species adapted to the humid, monsoon-influenced climate. The diversity of families such as Apocynaceae, Fabaceae, and Orchidaceae highlights the ecological richness of the region. These plants are crucial for maintaining the ecological balance and supporting local wildlife, including various butterfly species like the Lime Blue (Chiladeslaius) and Common Mormon (Papiliopolytes).

Conclusion

The flora of Nipani and its surrounding areas is diverse and ecologically significant. The documented species not only contribute to the local biodiversity but also support the local economy and culture. Further research is necessary to explore other aspects of biodiversity in the region, including fauna and ecosystem services.

References

1. Joshi, R. (2012). The Flora of Karnataka: A Comprehensive Guide. Karnataka University Press.
2. Palkar, A. M., Amate, S. S., Kurane, V. P., Chaus, F, Patil, S. B., & Potadar, P. (2020). The Biodiversity of Nipani: A Preliminary Study. Photography and Data Collection Team.
3. Sharma, P. (2014). Floral Diversity in Western Ghats of India. Botanical Society Press.
4. Singh, N. P., Lakshmi Narasimhan, P., Karthikeyan S., & Prasanna, P. V. (2001). Flora of Maharashtra State. Botanical Survey of India.

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Original Article

Renewable Energy for Sustainable Development: Opportunities and Challenges

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Abstract

The global energy sector is changing rapidly due to the urgent need to tackle climate change, cut greenhouse gas emissions, and achieve sustainable development. Renewable energy sources, including solar, wind, biomass, hydroelectric, and geothermal, have become practical and scalable alternatives to fossil fuels. They provide clean, plentiful, and increasingly affordable energy solutions. This review looks at the important role renewable energy plays in promoting sustainable development, especially in line with the United Nations Sustainable Development Goal 7 (SDG 7), which focuses on providing affordable, reliable, sustainable, and modern energy for everyone.

The paper emphasizes the environmental benefits of renewable energy, such as significant reductions in carbon dioxide emissions and lower levels of air and water pollution. It also examines the social and economic benefits, including job creation, rural development, improved energy access, and greater energy security. Key technologies like photovoltaic systems, offshore wind, energy storage solutions, grid modernization, and bioenergy innovations are identified as important factors shaping the future of renewable energy systems.

Despite its potential, the widespread use of renewable energy faces many challenges. These include variability, high upfront costs, complexities in integrating with the grid, policy obstacles, social opposition, and limited resources. Overcoming these challenges needs coordinated policy support, financial creativity, technology improvements, and global collaboration.

In summary, renewable energy is crucial for sustainable development. It offers a path toward a low-carbon, resilient, and fair global energy future. With ongoing investment and thoughtful policy implementation, renewable energy can significantly boost economic growth, protect the environment, and promote social fairness in the coming decades.

Keywords: *Renewable energy, Bioenergy, Environment, Sustainable development*

Introduction:

The global energy landscape is changing significantly. Renewable energy is becoming a key solution to the problems of climate change, environmental harm, and energy poverty. Transitioning to renewable energy is not just necessary for the environment; it also offers economic opportunities for sustainable development. As countries aim to meet their energy needs while reducing environmental damage, sources like solar, wind, hydro, geothermal, and biomass provide scalable solutions that promote clean energy and improve energy security.

Renewable energy technologies are crucial for achieving the United Nations' Sustainable Development Goals (SDGs), especially SDG 7, which calls for affordable and clean energy. This review looks at the role of renewable energy in sustainable development, focusing on its economic, social, and environmental benefits and challenges.

The world is undergoing a significant change in energy as we face serious environmental problems and the urgent need to address climate change. Countries are trying to meet rising energy demands while cutting greenhouse gas emissions.

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Renewable energy has become a vital solution for sustainable development. Sources like solar, wind, biomass, hydroelectric, and geothermal provide clean, abundant, and increasingly affordable alternatives to fossil fuels. They play an essential role in moving toward a low-carbon economy (IRENA, 2020). Sustainable development, as defined by the United Nations (UN), aims to meet human needs while protecting the environment for future generations. A core part of this vision is to ensure everyone has access to affordable, reliable, sustainable, and modern energy. This concept is captured in Sustainable Development Goal (SDG) 7 (United Nations, 2015). Achieving SDG 7 is crucial not just for giving energy access to billions who lack electricity, but also for reducing poverty, encouraging economic growth, and ensuring care for the environment.

Renewable energy technologies are key to this goal, offering a way to lessen the negative effects of climate change by decreasing dependence on fossil fuels and cutting carbon emissions. The International Renewable Energy Agency (IRENA) states that converting to renewable energy could reduce carbon dioxide (CO_2) emissions by up to 70% by 2050 while also generating millions of new jobs in green energy sectors (IRENA, 2021). Incorporating renewable energy into national energy systems is critical for the environment and presents economic opportunities. With the rapid drop in costs for renewable technologies, especially solar and wind, these energy sources are becoming more competitive with traditional fossil fuels. Additionally, renewable energy technologies foster local economic development by creating jobs, decreasing reliance on energy imports, and enhancing energy security (Blechinger et al., 2015).

Despite the potential of renewable energy, challenges persist. Problems like the variability of solar and wind power, high initial infrastructure costs, and the necessity for supportive policies are significant hurdles to scaling renewable energy worldwide (Kaldellis et al., 2016). Moreover, moving to renewable energy must go hand in hand with efforts to improve energy storage, modernize the grid, and enhance energy efficiency to tackle these challenges effectively.

This review provides a thorough analysis of renewable energy and its role in sustainable development. It looks into various renewable energy technologies, their potential impacts on economic, social, and environmental outcomes, and the challenges to their implementation. It also examines policy frameworks and strategies that could speed up the global transition to a renewable energy future.

Renewable Energy Technologies

Solar power through photovoltaic (PV) panels and concentrated solar power (CSP) has witnessed an exponential increase in the past decade. Solar energy is among the most promising renewable energy sources and is abundant in regions with much solar exposure, including the Middle East, Africa, and South Asia. According to International Renewable Energy Agency (IRENA) solar energy capacity has grown more than 20 times in the last decade, providing a significant contribution to global energy supplies (IRENA, 2020).

Apart from fossil fuel depletion, solar energy has its social benefits in generation of new job opportunities. The growth of solar industry is rapid and it has caused job employment in areas of maintenance, installation, and manufacture industries. For instance, the US solar industry has employed more than 250,000 people as of 2020 (U.S. Department of Energy, 2020).

Wind power has been proven to be one of the most cost-effective renewable energies, with on-and offshore wind farms playing critical roles in global energy production. (“Global Wind Energy Council [GWEC]”)

Apart from avoiding greenhouse gas emissions, wind energy has economic advantages, especially in rural communities, where such farms can provide employment and benefit local communities financially. The intermittency coupled with land use and aesthetic limitation factors present a significant blockade against overall implementation on a large scale (Kaldellis et al., 2016).

Biomass energy, which is obtained from organic material like wood, agricultural waste, and municipal solid waste, is a very adaptable type of renewable energy. It is used for electricity generation, heating as well as for transportation fuels (biofuels). Biomass energy also helps to reduce waste while at the same time producing energy (biomass plays a dual role in reducing waste and providing energy, thus it contributes to circular economies.

Bioenergy is most promising in Brazil and India where their massive agricultural industries can convert biomass into bio fuels such as ethanol and biodiesel. The World Bioenergy Association puts bio energy consumption at about 10% of the world’s total energy needs (WBA, 2020).

Hydropower remains the largest source of renewable sources of electricity, accounting for about 16% of the global electricity (International Hydropower Association, 2020). Large hydroelectric dams like China’s Three Gorges Dam produce massive amounts of electricity, whereas small hydro and micro-hydro alternatives provide decentralized power generation for rural communities.

However, environmental and social concerns have been attributed to large hydropower projects, including displacement of local communities, water pollution, and ecosystem disruption. However, more interest in small hydropower projects and run-off river hydro projects with minimal environmental impacts, and yet reliable energy generation is being expressed (Zhao et al., 2017).

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Geothermal energy uses heat from the earth's interior for electricity or direct heating purposes. Iceland, New Zealand, and the Philippine Islands are some of the leading countries in geothermal energy generation, with Iceland generating nearly 30% of its power from geothermal sources (Stefansson, 2005).

While geothermal energy is reliable and baseload, geological conditions limit its expansion. The geographical expansion of geothermal plants is best suited for regions located near the tectonic plate boundaries, and therefore poses geographical and economic constraints for a majority of the countries (Lund & Boyd, 2016).

Benefits of Renewable Energy for Sustainable Development

The transition to renewable energy is necessary to climate change mitigation. The carbon footprint of renewable energy sources is far much lower than that of fossil fuels. Renewable energy deployment could reduce global CO2 emissions by up to 70% by 2050 (IRENA, 2021).

In addition, renewable energy technologies have low dependency on water and produce negligible air and water pollution compared to conventional power plants. The move away from coals, oil, and gas also minimizes environmental damages linked to mining and fossil fuel production. Renewable energy technologies provide massive economic opportunities. The renewable energy sector is therefore one of the fastest growing industries in the world and is creating millions of jobs. For example, job creation in the renewable energy sector is projected to reach 85 million jobs by 2030 (ILO, 2020).

Renewable energy also enhances energy access in rural and remote areas where the construction of grid infrastructure is difficult and costly. Renewables also enhance energy access for rural and remote areas where extending the grid line may not be possible or economically viable, and solar home systems, off-grid wind, and small-scale hydropower projects ensure clean and affordable energy, thus improving the quality of life, alleviating poverty and promoting local economic development (Blechinger et al., 2015).

By diversifying energy sources, renewable energy strengthens national energy security by decreasing reliance on imported fossil fuel and shielding the economy from energy price fluctuations. Energy security is a diversification of energy sources, which renewable energy provides by ensuring national security against energy dependence on fossil fuel imports and exposure to energy price shocks, especially for countries that rely on energy imports such as India and Japan. Also, the decentralized mode of most of the renewable energy technologies (solar and wind) has the benefit of reducing the susceptibility of energy infrastructures to natural calamities, geopolitical conflicts, as well as other disturbances (Cherp et al., 2018).

Future Prospects of Renewable Energy and Sustainable Development

Renewable energy's future, in this sense, is closely associated with the world's sustainable development efforts. As the world faces unprecedented environmental challenges, the shift to renewable energy not only offers a solution to climate change but also holds the promise of a sustainable, more equitable and prosperous future. The future of renewable energy vis-à-vis sustainable development"

Technological Innovations and Advancements

Renewable energy future is heavily hinged on sustained innovation and developments in technology. In that regard, innovations in renewable energy generation, storage, and efficiency will be crucial to help overcome any existing limitations and boost its integration as global demand for clean energy grows.

Solar power remains to be one of the fasted growing renewable energy sources. Future solar energy prospects are based on the formulation of more efficient photovoltaic (PV) technologies that can provide better efficiency rates and low-cost perovskite solar cells than silicon solar cells (Kumar et al., 2021). Advancements in solar energy storage technologies, including next-generation batteries and grid-scale storage solutions, are anticipated to mitigate solar power's intermittency issues, thus making it a dependable source of baseload power (IRENA, 2020).

Wind energy will soon take off rapidly because of the development of wind farms located in the sea. Offshore wind has a greater and more constant wind speed than onshore wind, so it is becoming more preferred for energy generation. Floating wind turbine technologies that are capable of floating on waters too deep for conventional turbines present a major innovation in wind power (Ahlstrom et al., 2019). Given the continued decline in costs of offshore wind technology, offshore wind will likely be the dominant clean energy source in the future decades.

Storage and management of electricity is one of the significant hurdles against massive deployment of renewable energy. Energy storage breakthroughs are expected to play a pivotal role in stabilizing the grid and improving the reliability of renewable energy systems like solid-state batteries, compressed air energy storage (CAES), and green hydrogen (Luo et al., 2015). Electrically grids modernization, making them flexible, smarter, and capable of decentralized energy source capacity, is crucial in large-scale renewable energy integration (Pereira et al., 2020). Bioenergy still holds a promise for clean and sustainable energy. Bioenergy remains a promising solution to clean and sustainable energy. Waste-to-energy technologies will also become more pivotal as cities or industries look to using their waste as a resource to generate power and heat while also controlling waste's environmental impacts.

Policy and Regulatory Support

The future of renewable energy also depends on strong policy frameworks and regulatory measures that can set favorable conditions for investment, innovation, and mass adoption. Governments must play a central role in driving the transition to a low-carbon future. The implementation of carbon pricing mechanisms, including carbon taxes or cap-and-trade, is a crucial component in making fossil fuel investments less economically attractive relative to renewable energy investments. They also correct the economic imbalance that currently benefits fossil fuels over renewable energy sources (Rabe, 2018). More countries are also projected to implement carbon pricing mechanisms in the coming years to quicken the pace of decarbonizing their energy sectors.

Government subsidies and incentive programs will continue to play significant role in making renewable energy technologies more affordable and accessible. Many countries already implemented feed-in tariffs, renewable portfolio standards, and tax credits to encourage renewable energy adoption (IRENA, 2020). With decreasing costs of renewable technologies, the subsidies can transition toward supporting energy storage, grid infrastructure, and fostering clean energy-related innovations.

International cooperation will be critical to scaling renewable energy globally as the global society acknowledges the immediacy of coping with climate change (Parag & Sovacool, 2016). Multilateral agreements, exemplified by the Paris Agreement, will continue to play a role in urging countries to set targets for renewable energy and to share knowledge, technology, and resources required to expedite the global energy transition (UNFCCC, 2015). Such global cooperation on renewable energy projects in developing countries will also ensure a fair distribution of benefits of renewable energy.

Economic Opportunities and Challenges

The shift to renewable energy provides significant economic chances, especially in job creation, economic diversity, and energy security.

1. Job Creation and Economic Growth

The renewable energy sector is expected to drive substantial job creation in the coming decades. According to the International Labour Organization (ILO), renewable energy could create over 85 million jobs worldwide by 2030 (ILO, 2020). These jobs cover various areas, including manufacturing, installation, maintenance, and research and development. By investing in renewable energy infrastructure, countries can also boost economic growth, especially in areas where jobs are hard to find.

2. Decentralization of Energy Production

The move toward decentralized renewable energy systems, like rooftop solar panels and local wind farms, allows communities and individuals to become more energy self-sufficient. This decentralization lessens dependence on centralized energy grids, increases local resilience, and supports energy security. In developing countries, small-scale renewable systems can provide affordable and reliable energy to remote areas, helping reduce poverty and improve living conditions (Blechinger et al., 2015).

3. Energy Access and Equity

One of the greatest benefits of renewable energy is its ability to offer affordable and sustainable energy to underserved areas. Decentralized renewable energy systems can be quickly installed in places where traditional power infrastructure is missing, ensuring that people in rural and remote locations have access to electricity. This access can spur economic growth, enhance health outcomes, and support education, especially in developing nations (UNDP, 2017).

Challenges in Scaling Renewable Energy and Sustainable Development

Shifting to renewable energy is a vital part of global efforts to promote sustainable development. Renewable energy can help tackle climate change, decrease energy poverty, and drive economic growth. However, despite its great potential, expanding renewable energy systems comes with numerous challenges. These challenges, including technical issues, financial obstacles, regulatory problems, and social resistance, must be tackled to realize renewable energy's full potential for sustainable development. This section explores the main challenges related to scaling renewable energy technologies and how they connect with broader sustainable development goals (SDGs).

1. Intermittency and Reliability of Renewable Energy Sources

A major challenge for renewable energy, especially solar and wind power, is their unpredictability. Unlike fossil fuels or nuclear energy, which provide consistent and predictable power, renewable energy production relies on natural resources that vary with time of day, weather, and seasons. This unpredictability can cause grid instability and an unreliable electricity supply, making it difficult to integrate renewable energy into the existing energy mix (Pereira et al., 2020).

• Energy Storage Technologies: Developing cost-effective and efficient energy storage options, like lithium-ion batteries, pumped hydro storage, and compressed air energy storage (CAES), is vital for balancing energy supply and demand. These storage systems can hold surplus energy produced during times of high generation (like sunny or windy periods) and release it when demand exceeds supply (Luo et al., 2015).

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• Grid Modernization: Updating grids to "smart grids" that feature sensors and advanced forecasting tools can help manage the variability of renewable energy production and enhance energy system stability (Pereira et al., 2020).

2. High Initial Investment and Financing Challenges

The shift to renewable energy technologies requires significant upfront investment in infrastructure, including solar panels, wind turbines, storage systems, and grid improvements. While renewable energy sources may be cost-competitive over time, the initial capital needed for implementation remains a major barrier, particularly in developing nations where access to affordable funding is low (IRENA, 2020).

According to the International Renewable Energy Agency (IRENA), the global transition to renewable energy needs an annual investment of $2.4 trillion through 2050 to achieve climate and energy objectives (IRENA, 2021). Many developing countries face considerable funding gaps, as they lack the financial resources or institutional support for large-scale renewable energy projects.

• Innovative Financing Models: Public-private partnerships (PPPs), green bonds, and international climate financing tools like the Green Climate Fund (GCF) can offer solutions for funding renewable energy projects. These financing models can help reduce the risks associated with renewable energy investments (IRENA, 2021).

• Policy Support and Incentives: Governments can encourage investment by providing tax benefits, subsidies, and feed-in tariffs that lower the financial risk for investors. Strong and clear policy guidelines are essential for attracting both local and international investments in renewable energy.

3. Energy Storage and Grid Integration Challenges

While renewable energy storage solutions are important for addressing intermittency, there are technical issues when integrating renewable energy into current energy grids. Most electricity grids are built for centralized, fossil-fuel-based energy production and cannot efficiently handle the large-scale integration of decentralized renewable energy systems. The weak transmission infrastructure in many areas also limits the delivery of renewable energy from production sites to consumers (Zhao et al., 2017).

• Grid Modernization and Upgrades: Updating the grid infrastructure is necessary to support both decentralized renewable energy and distributed energy resources. Modern grid systems need to balance loads dynamically, monitor energy in real-time, and manage demand-side activities to effectively distribute energy and prevent blackouts (Pereira et al., 2020).

• Regional Energy Integration: Cross-border electricity networks can solve regional variability by sharing renewable energy between neighboring countries with different generation profiles. This approach can also improve energy security (IRENA, 2020).

4. Social and Political Resistance

The shift to renewable energy often meets social and political pushback, especially in areas where fossil fuel industries are key to jobs and economic development. In many countries, the fossil fuel sector is still a major income source, and workers are understandably worried about job losses as renewable energy technologies grow. Additionally, strong interests in the fossil fuel sector can obstruct policies that support renewable energy (Rabe, 2018).

• Just Transition Policies: Governments need to create and enforce just transition policies that help fossil fuel workers retrain and find new jobs in the renewable energy sector. These policies could include job retraining programs, relocation help, and new job creation in developing areas like energy efficiency, renewable energy manufacturing, and grid management (ILO, 2020).

• Public Awareness Campaigns: Raising public awareness about the environmental, economic, and social advantages of renewable energy is key to building public support and political motivation. Involving local communities in planning and decision-making for renewable energy projects can also help reduce opposition.

5. Lack of Infrastructure and Technological Capacity in Developing Countries

Many developing countries struggle to scale renewable energy due to insufficient infrastructure, technical expertise, and skilled labor needed for deploying and maintaining renewable energy systems. The lack of reliable energy access in rural regions makes this situation worse since basic infrastructure is often missing, which complicates the implementation of renewable energy solutions (Blechinger et al., 2015).

• Capacity Building and Technical Assistance: Organizations like the United Nations Development Programme (UNDP) and IRENA can support developing countries by offering technical help, capacity-building programs, and training for workers in renewable energy. These efforts can improve the local workforce's skills in installing and maintaining renewable energy systems.

• Decentralized Renewable Energy Solutions: Small-scale, off-grid renewable energy systems, such as solar home systems and mini-grids, can be effective in rural and remote areas where large infrastructure projects are impractical. These decentralized systems can also create economic opportunities in underserved communities (UNDP, 2017).

6. Environmental and Land Use Conflicts

Large-scale renewable energy projects, like hydropower dams and wind farms, can have significant environmental impacts. These include habitat destruction, water resource depletion, and the displacement of local communities. Such environmental and land use issues can lead to public opposition and slow the development of renewable energy projects (Kaldellis et al., 2016).

• Environmental Impact Assessments (EIA): Conducting thorough EIAs and engaging in proper planning along with community consultation can reduce the environmental and social impacts of renewable energy projects. Transparent decision-making and responsible land use are essential for ensuring that renewable energy projects are sustainable and accepted by the community (Kaldellis et al., 2016).

7. Technological Limitations and Resource Availability

The availability of resources needed for some renewable energy technologies, like rare earth elements for solar panels and wind turbines, can create challenges in scaling renewable energy. Resource scarcity and supply chain issues can impact the production and use of renewable technologies (Ahlstrom et al., 2019).

• Research and Development (R&D): Ongoing investment in R&D is important for finding alternative materials and improving the efficiency of renewable energy technologies. Additionally, increasing recycling rates and resource efficiency in the renewable energy sector can help manage the risks related to resource scarcity (IRENA, 2020).

Scaling renewable energy to meet global sustainable development goals faces numerous challenges, including technical issues related to intermittency and storage, as well as political, financial, and social barriers. However, tackling these challenges through innovation, supportive policies, and international cooperation can unlock renewable energy's potential to create a more sustainable, fair, and resilient energy future. Governments, industries, and communities need to collaborate to overcome these obstacles and speed up the global shift to renewable energy.

Conclusion

Renewable energy has become a key part of sustainable development, providing a way to achieve cleaner, more resilient, and inclusive energy systems. While significant strides have been made, challenges related to intermittency, infrastructure, and policy need to be solved to speed up the global transition to renewable energy. With continued technological advancements, policy backing, and investment, renewable energy can meet the rising global energy demand while helping to achieve the SDGs.

The future of renewable energy offers tremendous opportunities for advancing sustainable development in economic, environmental, and social areas. Progress in technology, supported by favorable policies and global cooperation, will lead to a future where renewable energy becomes the main source of global power generation. By addressing issues like intermittency, financing, and political resistance, the global community can fast-track the shift to a low-carbon future, ensuring that everyone benefits from renewable energy.

References

1. Ahlstrom, M., Neumann, A., & Howell, M. (2019). "The Future of Offshore Wind Energy." Renewable and Sustainable Energy Reviews, 98, 305-318.
2. Blechinger, P., Henttonen, M., & Pomfret, R. (2015). "The Role of Renewable Energy in Promoting Rural Development." Renewable and Sustainable Energy Reviews, 42, 1-12.
3. Cherp, A., Jewell, J., & Goldthau, A. (2018). "Governing the Transition to Renewable Energy." Nature Energy, 3, 765-774.
4. Global Wind Energy Council (GWEC). (2021). "Global Wind Report 2021." Global Wind Energy Council.
5. International Labour Organization (ILO). (2020). "Renewable Energy and Jobs: Annual Review 2020." International Labour Organization.
6. International Renewable Energy Agency (IRENA). (2020). "Renewable Capacity Statistics 2020." International Renewable Energy Agency.
7. International Renewable Energy Agency (IRENA). (2021). "World Energy Transition Outlook 2021." International Renewable Energy Agency.
8. Kaldellis, J., Zafirakis, D., & Kavadias, K. (2016). "The Challenges and Opportunities of Wind Power." Renewable Energy, 95, 508-519.
9. Kempener, R., van der Burgt, P., & Jäger-Waldau, A. (2014). "Renewable Energy: Policy and Regulatory Challenges." Renewable and Sustainable Energy Reviews, 30, 263-273.
10. Kumar, A., Verma, S., & Singh, R. (2021). "Advancements in Solar Energy Technologies: Efficiency, Materials, and Storage." Renewable Energy Journal, 45(7), 1001-1013.
11. Luo, X., Wang, J., Dooner, M., & Clarke, J. (2015). "Overview of Current Energy Storage Technologies and the Applications." Energy, 65, 1-19.
12. United Nations (2015). "Transforming Our World: The 2030 Agenda for Sustainable Development." United Nations.

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Original Article

Frontiers of Nanomaterials: Properties, Design and Applications

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Abstract

Nanomaterials are a unique class of materials possessing at least one dimension between 1 and 100 nm. At this scale, materials exhibit extraordinary physical, chemical, optical, mechanical, and catalytic properties that differ significantly from their bulk counterparts. These properties arise primarily from high surface-to-volume ratios and quantum confinement effects. Nanomaterials can be rationally designed and tuned through precise control of size, shape, synthesis conditions, and surface fictionalization. This review summarizes the history of nanomaterials, synthesis strategies (top-down and bottom-up approaches), distinctive nanoscale properties, major classes of nanomaterials particularly carbon-based and 2D materials and their applications in energy, medicine, electronics, catalysis, and environmental remediation. Key challenges and future perspectives are also discussed.

Keywords: *Top-down approach, Bottom-up approach, Carbon Based Nano-materials, 2-D Nano-materials*

Introduction:

Nanomaterials are defined as materials with at least one dimension in the range of 1–100 nm. To visualize this scale, one nanometer corresponds approximately to five silicon atoms or ten hydrogen atoms arranged in a line. At this dimension, size-dependent phenomena dominate material behavior.

Although the formal scientific exploration of nanotechnology began in the 20th century, nanoscale materials were unknowingly used in ancient times. Examples include asbestos nanofibers reinforcing ceramics, PbS nanoparticles in Egyptian hair dyes, and metallic nanoparticles in the Roman Lycurgus Cup that produce dichroic color effects.

The conceptual foundation of modern nanotechnology is often attributed to Richard Feynman, whose 1959 lecture "There's Plenty of Room at the Bottom" envisioned manipulation of matter at the atomic scale. The term "nanotechnology" was later introduced in 1974 by Norio Taniguchi.

Significant progress occurred after the development of advanced characterization tools such as scanning tunneling microscopy (STM) and atomic force microscopy (AFM), enabling atomic-scale imaging. Today, nanotechnology permeates materials science, electronics, medicine, energy systems, and environmental engineering.

Synthesis Approaches for Nanomaterials

Nanomaterials are typically synthesized through two principal strategies: top-down and bottom-up approaches.

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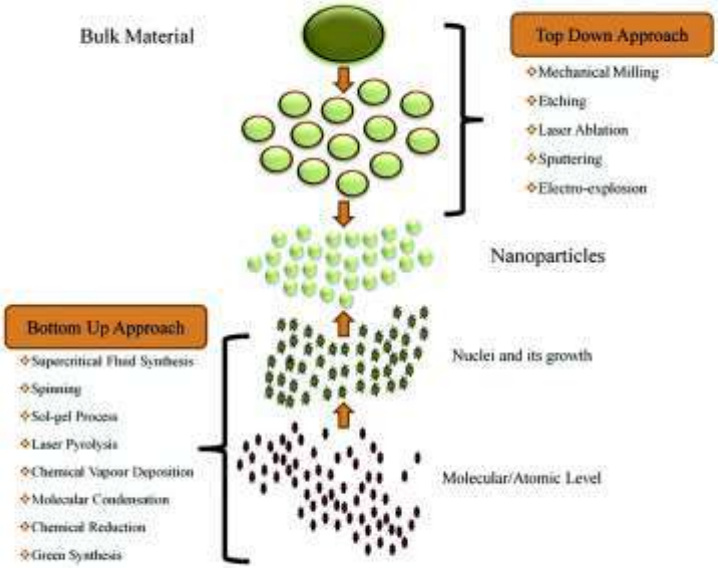
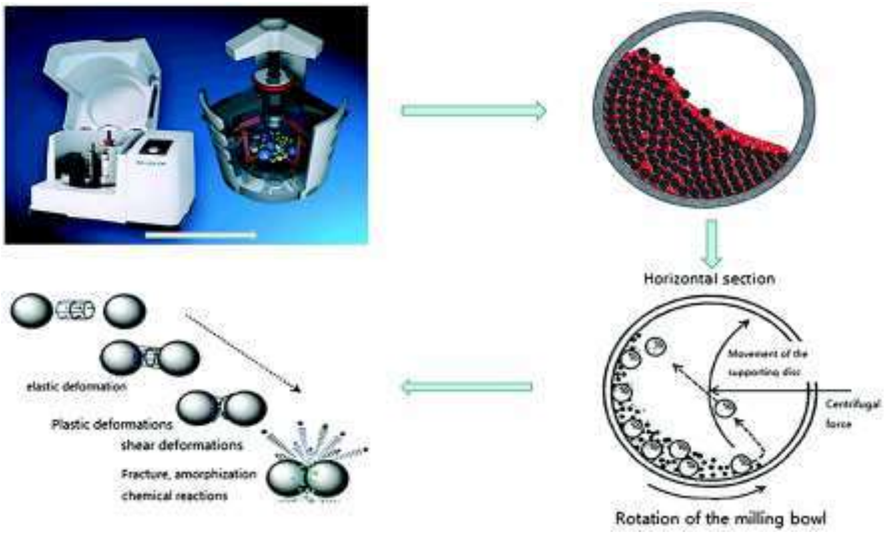


1 Top-Down Approaches

In top-down methods, bulk materials are broken down into nanoscale structures. These approaches include:

- **Mechanical milling** reduces bulk materials to nanoscale particles through high-energy ball collisions. It is widely used for nanocomposites and alloy production but may introduce structural defects.



- **Electro spinning** produces nano fibers from polymer solutions under strong electric fields. Coaxial electro spinning enables the formation of core–shell nanostructures.

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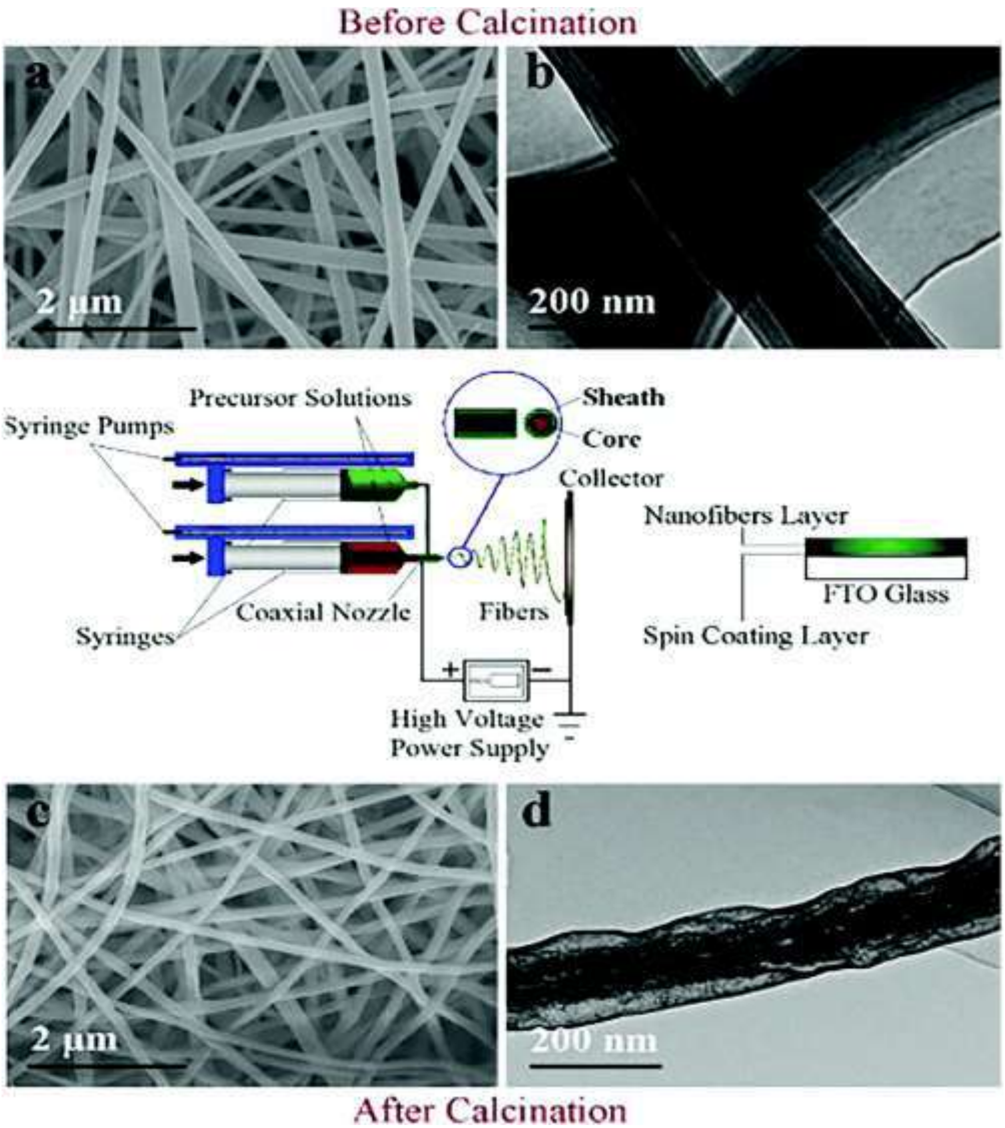
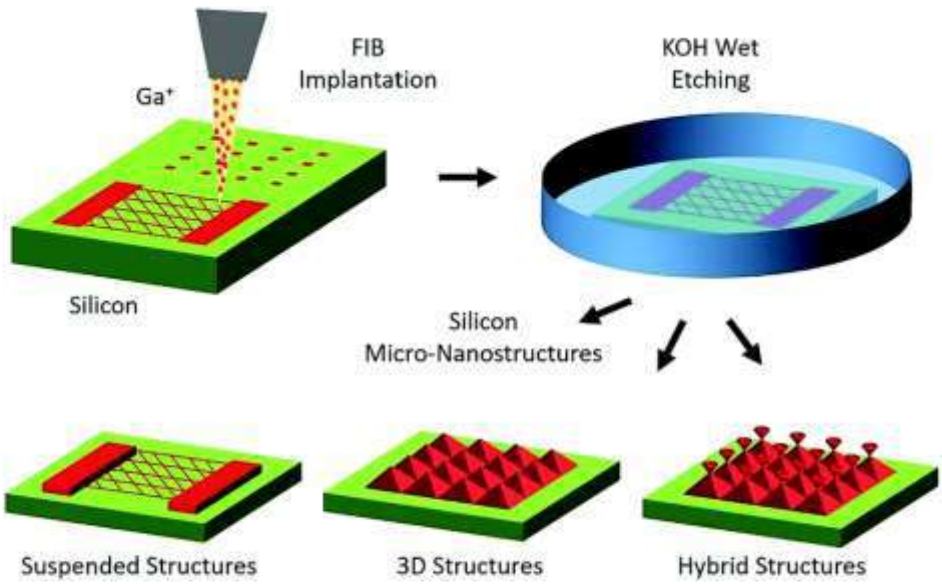


- **Lithography**, including photolithography and electron-beam lithography, enables fabrication of nano architectures with precise pattern control.



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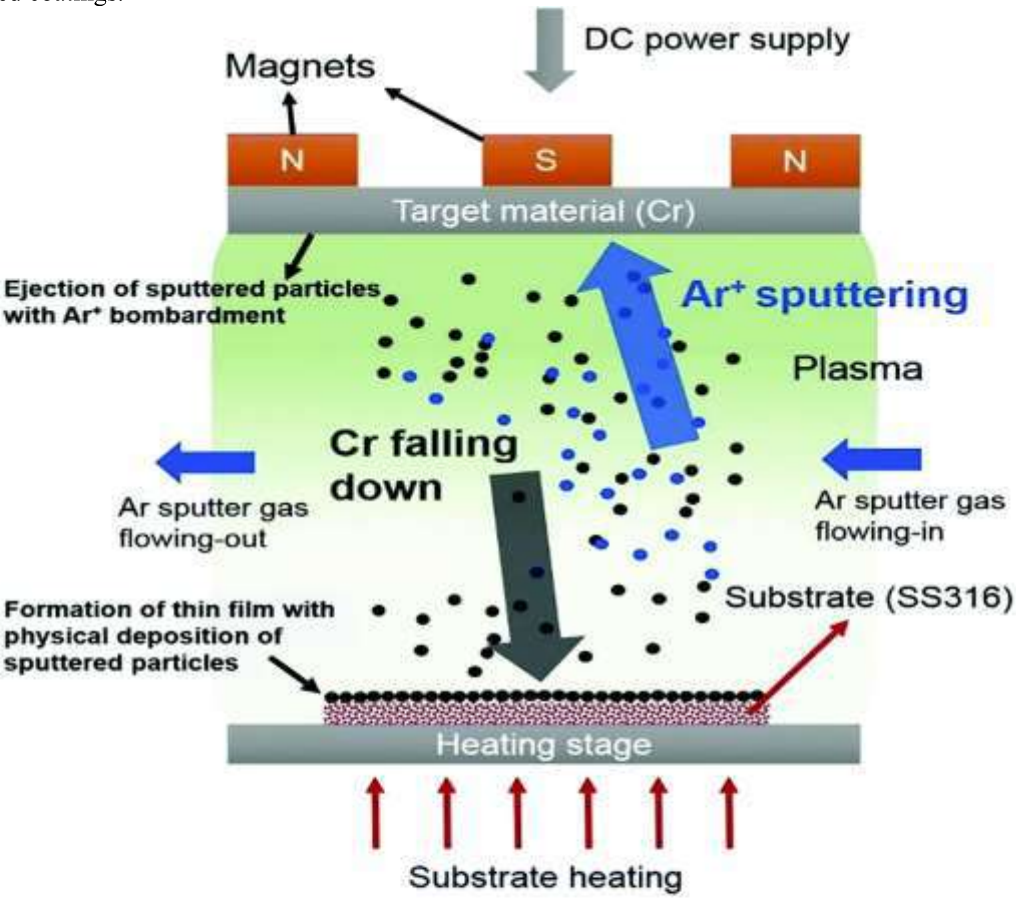
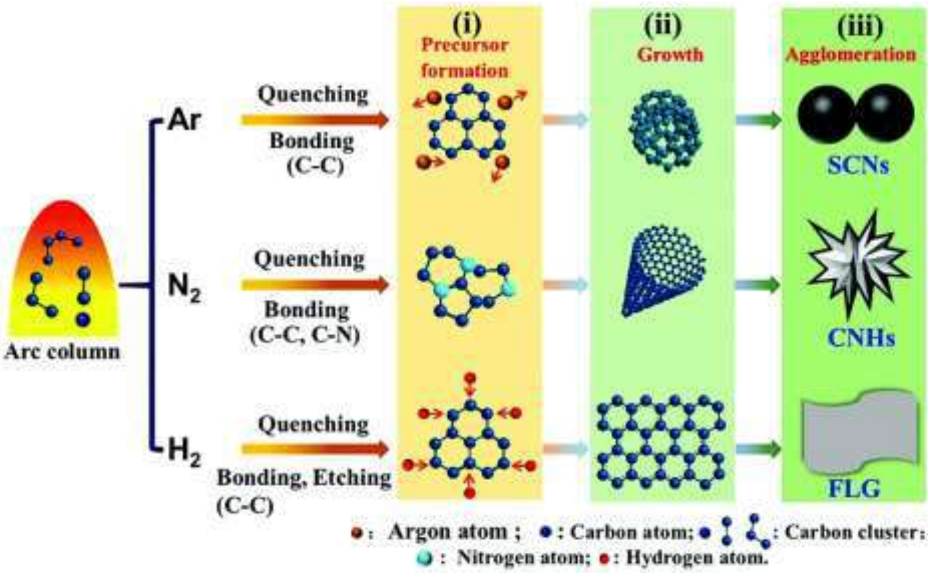
- Sputtering: Sputtering deposits thin films via ion bombardment of a target material, producing uniform nano structured coatings.



- Arc discharge: **Arc discharge** is widely used for synthesizing carbon-based nano-materials such as fullerenes and carbon nanotubes.



- Laser ablation: **Laser ablation** generates nanoparticles through high-energy laser irradiation of a target. It is considered a clean method, especially for noble metal nanoparticles, as it avoids surfactants.

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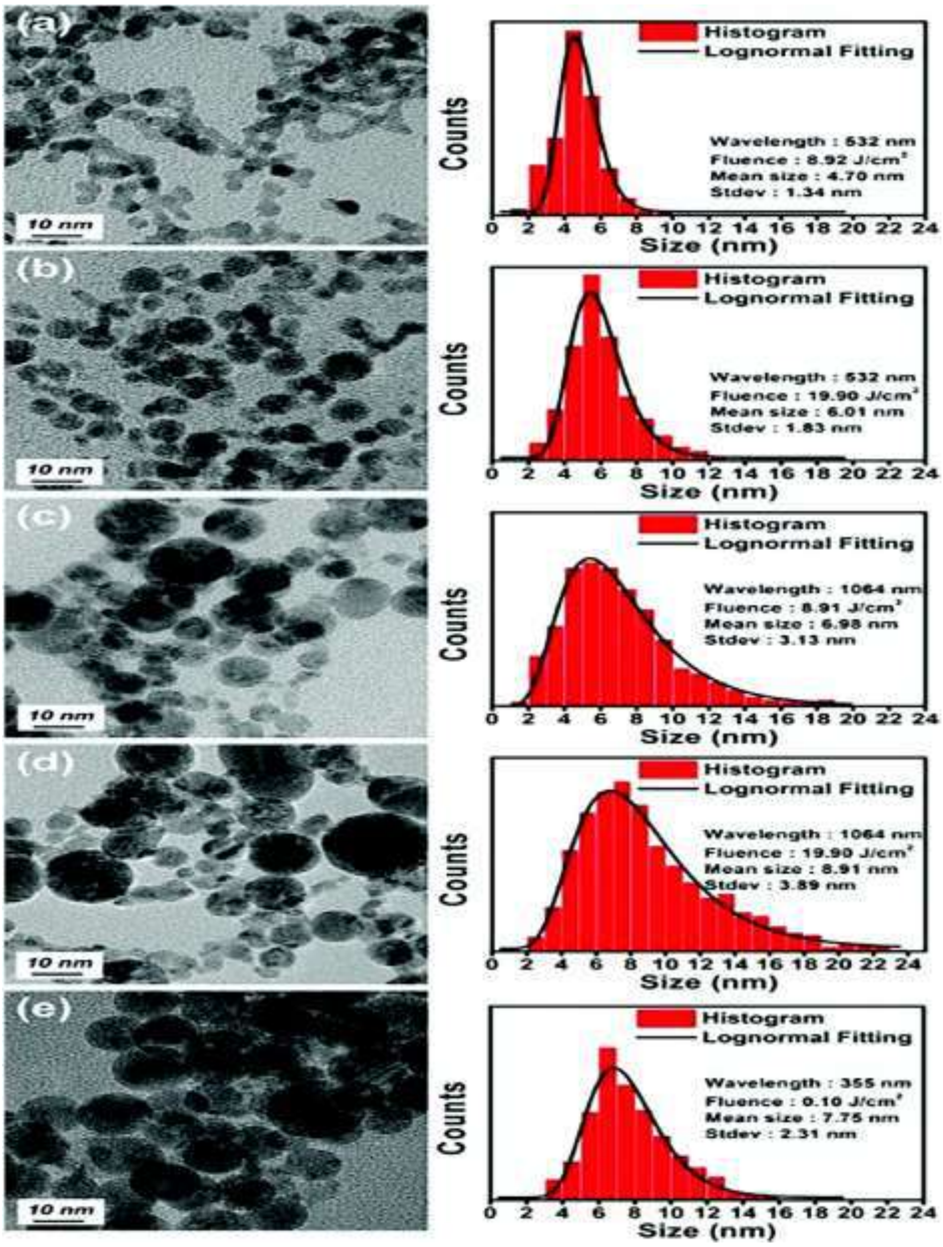

Mechanical milling reduces bulk materials to nanoscale particles through high-energy ball collisions. It is widely used for nanocomposites and alloy production but may introduce structural defects.

Electrospinning produces nanofibers from polymer solutions under strong electric fields. Coaxial electrospinning enables the formation of core–shell nanostructures.

Lithography, including photolithography and electron-beam lithography, enables fabrication of nanoarchitectures with precise pattern control.

Sputtering deposits thin films via ion bombardment of a target material, producing uniform nanostructured coatings.
Arc discharge is widely used for synthesizing carbon-based nanomaterials such as fullerenes and carbon nanotubes.
Laser ablation generates nanoparticles through high-energy laser irradiation of a target. It is considered a clean method, especially for noble metal nanoparticles, as it avoids surfactants.
Top-down approaches are generally scalable but may suffer from limited control over defects and morphology.

2. Bottom-Up Approaches

Bottom-up methods construct nanostructures atom-by-atom or molecule-by-molecule. These methods offer better control over size, morphology, and crystallinity.

Key bottom-up techniques include:

- Chemical vapor deposition (CVD)

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- Hydrothermal and solvothermal synthesis
- Sol–gel method
- Soft and hard templating

Chemical Vapor Deposition (CVD) involves chemical reactions of vapor-phase precursors on heated substrates to produce thin films or nanostructures. CVD is particularly important for synthesizing carbon nanotubes and graphene. Catalyst selection significantly influences structure and layer number.

Hydrothermal and solvothermal methods involve reactions in sealed vessels at elevated temperature and pressure. These methods are versatile for producing nanowires, nanorods, nanosheets, and nanospheres.

Sol–gel processing converts metal alkoxide precursors into colloidal sols and eventually gels through hydrolysis and condensation reactions. After drying and calcination, nanostructured metal oxides are obtained. The process is cost-effective and suitable for coatings and powders.

Templating methods (soft and hard templates) enable fabrication of ordered mesoporous and nanoporous materials. Soft templates include surfactants and block copolymers, while hard templates use solid structures such as silica or carbon frameworks.
Bottom-up approaches provide higher structural control but may require complex processing conditions.

Unique Features of Nanomaterials
Nanomaterials exhibit properties fundamentally different from bulk materials due to quantum and surface effects.
1 High Surface Area
Nanomaterials possess extremely high surface-to-volume ratios, enhancing catalytic activity, adsorption capacity, and reactivity.
2 Quantum Effects
When particle sizes approach the exciton Bohr radius (typically 1–10 nm), quantum confinement effects arise. This leads to size-dependent optical and electronic properties, especially in semiconductor quantum dots.
3. Tunable Optical Properties
Metal nanoparticles exhibit localized surface plasmon resonance (LSPR), leading to color changes with particle size and shape. For example, bulk gold appears yellow, whereas gold nanoparticles may appear red or purple.
4 Enhanced Mechanical Strength
Reduced defect density and improved crystallinity at nanoscale often result in superior mechanical strength compared to bulk materials.
5 Improved Electrical and Thermal Conductivity
Certain nanomaterials, such as graphene, demonstrate exceptional electrical and thermal conductivity.
6 Magnetic Changes
Magnetic behavior may change dramatically at nanoscale. Some materials exhibit superparamagnetism or altered magnetic ordering.
7 Antimicrobial Activity
Many nanomaterials exhibit antiviral, antibacterial, and antifungal activity, making them useful in biomedical and environmental applications.

Major Classes of Nanomaterials
1 Carbon-Based Nanomaterials
Carbon nanomaterials are among the most studied due to their structural diversity and outstanding properties. These include:
- Fullerenes
- Carbon nanotubes (CNTs)
- Graphene
- Carbon quantum dots
- Carbon nanohorns

Fullerenes
Fullerene were discovered in 1985 and represent spherical carbon cages composed of sp^2-hybridized carbon atoms. The most well-known example is C_{60}, consisting of 12 pentagons and 20 hexagons arranged in icosahedral symmetry.
Fullerenes can be chemically modified in two main ways:
- Endohedral doping (atoms encapsulated inside the cage)
- Exohedral functionalization (surface modification)

Encapsulation allows stabilization of reactive atoms such as lithium or lanthanides, making fullerenes promising for hydrogen storage, nanoelectronics, and energy applications.

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Carbon Nanotubes (CNTs)

CNTs exhibit exceptional tensile strength, high electrical conductivity, and large surface areas. However, their performance is sensitive to defects, chirality, and agglomeration.

Graphene

Graphene is a single layer of sp^2-bonded carbon atoms arranged in a hexagonal lattice. It exhibits extraordinary electrical conductivity, mechanical strength, and thermal transport properties. Its isolation triggered exploration of many other 2D materials.

2 Two-Dimensional (2D) Materials

Beyond graphene, ultrathin 2D materials include:

- Silicene
- Borophene
- Antimonene
- MXenes
- 2D metal–organic framework (MOF) nanosheets
- Boron nitride nanosheets

These materials offer high surface area, tunable band gaps, and potential applications in electronics, catalysis, and energy storage. However, experimental validation and scalable synthesis remain challenging.

3 Metal-Based Nanomaterials

Metal nanoparticles and metal oxides are widely used in catalysis, energy conversion, sensing, and water splitting. Their small size enhances surface-active sites and improves reaction kinetics.

4. Core–Shell and Nanoporous Materials

Core–shell structures optimize material utilization by combining different functionalities while reducing usage of critical elements. Nanoporous materials provide high internal surface areas and efficient mass transport pathways.

Applications of Nanomaterials

Nanomaterials have penetrated multiple technological sectors.

1 Medicine and Nanomedicine

Nanoparticles enable targeted drug delivery, improved imaging, and antimicrobial coatings. Clinically approved nanoformulations such as liposomal drugs demonstrate the practical utility of nanomedicine.

2 Energy Generation and Storage

Nanomaterials enhance:

- Lithium-ion batteries
- Super capacitors
- Hydrogen fuel cells
- Solar cells
- Water-splitting catalysts

High surface areas and rapid charge transport improve energy efficiency and storage capacity.

3 Electronics and Computing

Nano-engineered materials enable smaller, faster, and more efficient electronic devices, including nano-field-effect transistors and flexible electronics.

4 Environmental Remediation

Nanomaterials are applied in:

- Water purification
- Air filtration
- Heavy metal removal
- Pollutant degradation

Their high reactivity and adsorption capacity make them effective environmental solutions.

5. Industrial and Consumer Products

Commercial applications include:

- Scratch-resistant coatings
- Self-cleaning surfaces
- Sunscreens (ZnO and TiO_2 nanoparticles)
- High-definition display pigments

Challenges in Nanomaterials Development

Despite rapid progress, several challenges remain:

1 Structural Defects

Defects reduce mechanical strength and electrical performance, especially in CNTs and graphene.

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2 Cost and Scalability
High-quality nanomaterials often require sophisticated and expensive synthesis methods, limiting large-scale production.
3 Agglomeration
Nanoparticles tend to aggregate due to van der Waals forces and high surface energy, reducing accessible surface area and performance.
4 Limited Experimental Validation of 2D Materials
Many predicted 2D materials lack comprehensive experimental characterization.
5 Toxicity and Environmental Concerns
The long-term biological and environmental impacts of nanomaterials remain incompletely understood. Systematic studies on nanoparticle–cell interactions are essential for safe commercialization.
6. Critical Element Dependency
Many nanotechnologies rely on rare or endangered elements such as lithium and rare-earth metals. Developing sustainable alternatives is crucial.

Future Perspectives
The future of nanotechnology lies in:
- Designing defect-free and precisely controlled nanostructures
- Developing green and scalable synthesis methods
- Constructing 3D architectures to improve mass and electron transport
- Reducing reliance on critical raw materials
- Advancing safe-by-design nanomaterials

Nanotechnology is expected to play a transformative role in clean energy production, hydrogen storage, advanced catalysis, nanomedicine, and environmental sustainability.

Conclusion
Nanomaterials represent a transformative frontier in materials science. Their unique size-dependent properties—including high surface area, quantum confinement effects, tunable optical behavior, enhanced mechanical strength, and superior catalytic activity—enable applications across medicine, energy, electronics, environmental remediation, and industrial manufacturing.

Synthesis strategies, categorized as top-down and bottom-up approaches, provide pathways to engineer nanostructures with tailored properties. Carbon-based nanomaterials, 2D materials, metal-based nanostructures, and core–shell architectures have shown particularly promising performance.

However, challenges related to defects, scalability, agglomeration, toxicity, and critical material dependence must be addressed to ensure sustainable technological advancement. With continued innovation in synthesis, characterization, and application design, nanotechnology will remain central to addressing global challenges in energy, healthcare, and environmental protection.

References:
1. F. J. Heiligtag and M. Niederberger, Mater. Today, 2013
2. P. N. Sudha, K. Sangeetha, K. Vijayalakshmi and A. Barhoum, Emerging Applications of Nanoparticles and Architecture Nanostructures, Elsevier, 2018
3. P. Khanna, A. Kaur and D. Goyal, J. Microbiol. Methods, 2019, 163, 105656
4. R. P. Feynman, Eng. Sci., 1960, 23, 22–36
5. M. Tayebi and B.-K. Lee, Renewable Sustainable Energy Rev., 2019, 111, 332–343

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Original Article

Impact of Urbanization on the Physicochemical Parameters of Varthur Lake in Bengaluru City, Karnataka, India

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Abstract

Water is a natural resource which is decisive for the survival of living organisms. Lake water is a source of drinking and domestic use for rural and urban population of India. Quality of water is determined based on characteristics such as physical (temperature, color, taste, odor) chemical, biological characteristics and compare with standard value for drinking water which is recommended by WHO (world health organization) and BIS (bureau of Indian standards). The quality of water is also determined based on Chemical parameters. Chemical parameters are pH, turbidity, total dissolved solids, total suspended solids, nitrates, sulphates, iron, total hardness, Calcium carbonate, magnesium, Dissolved Oxygen, Biochemical Oxygen Demand, total alkinity, electrical conductivity, chlorides. The study of Varthur lake, Bengaluru was done during the month of October 2025. Obtained water quality index is poor which can be used for irrigation and industrial purposes after secondary level treatment with activated sludge process and secondary sedimentation tank.

Keywords: *Varthur Lake, Water quality, Lake Water, Irrigation, Physico - chemical characters*

Introduction:

Lakes plays a pivotal role in serving the needs of agriculture, irrigation, drinking, domestic uses, industries and other related purposes. Lakes were preserved and maintained to help the man kind at the time of water crisis during long dry periods and droughts. The location of Varthur Lake is at 12°56'55.2"N 77°44'20.5"E (DMS), with an area of 445.8 acres. Varthur Lake is one of the highly polluted lakes in Bengaluru now. It has become more or less a sewage tank because of untreated sewage water entering into the lake through various inlets. Varthur Lake is situated in the south taluk of Bangalore district. It has a large surface area and is the main irrigation source to the nearby agricultural fields and supports a wide variety of flora and fauna. Due to rapid urbanization the land around the lake is used as a dumping ground by builders and housing societies in the area. Since the early 2000s, nearby areas have been dumping untreated sewage and industrial waste into the lake unchecked. The presence of industrial chemicals in the water causes the lake surface to catch fire regularly and during the rainy season the lakes will be full of foam. The foam is mainly due to high content of oil and grease substances. Varthur collects the maximum amount of sewage water, most of it untreated. High levels of Ecoli bacteria found in untreated sewage percolates the groundwater table and causes waterborne diseases (1). Varthur lake has been receiving about >40% of the city sewage for over 50 years resulting in eutrophication. There has been a phenomenal increase in the algal growth, dissolved oxygen depletion and malodor generation, and an extensive growth of exotic macrophytes that covers about 80% of the lake in the dry season. Macrophytes grow in or near water and are emergent, submergent, or floating forming a vital component of lake ecosystems. In recent times urban waterbodies are being used for disposal of sewage, etc. Sustained inflow beyond the assimilative capacity of waterbodies has lead to eutrophication resulting in the profuse growth and spread of invasive species.

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The uncontrolled release of nitrogen to the environment is known to cause serious pollution problems. Nitrates in surface water has been attributed to wastewater outfalls (sewage ingress) and agricultural runoff (4,5). The conversion rates from one form to another as well as their uptake/release by various biological agents and their quantification are often not carried out. Earlier estimates indicate that Varthur lake receives about 500 MLD of sewage (6). The present study deals Impact of Urbanization on the Physicochemical Parameters of Varthur Lake in Bengaluru City, Karnataka, India.

Materials and methods:

Water samples for analysis were collected from varthur Lake in polythene bottles as per standard procedure. The samples analysis was conducted after two days of collection. The analysis was done as per IS3025 standards. The analysed physicochemical parameters and heavy metals were compared with the WHO and ISI Standards.

Result and discussion:

The physico-chemical examination of the water samples carried out for the various water quality parameters. In the present study the data revealed that there were considerable variations in the quality with respect to their physicochemical characteristics. Temperature of water is basically important because it effects biochemical reactions in aquatic organisms (7). A rise in temperature of water leads to the speeding up of chemical reactions in water, reduces the solubility of gases and amplifies the tastes and odour. Temperature of water found in the range 28.1 to 29.6 ^{0}C. It is also observed from the present study that, the colour of the lake water is also greyish black to Dark blue because of Weeds and green algal growth population. Turbidity is a measurement of the cloudiness of water. Cloudiness is caused by material suspended in water. Clay, silt, organic matter, plankton and other microscopic organisms cause turbidity in natural water. This has been recognized as a valuable limiting factor in the biological productivity of the water bodies (8). In the present study the turbidity found in the range between 14 to 30.9 NTU. It exceeds the permissible limit above 5 NTU consumer acceptance decreases. Electrical Conductivity (EC) is higher the concentration of acid, base and salts in water, the maximum permissible limit of 500µs/cm, in drinking water as recommended by WHO. In this study the value of EC found in the range 1170 to 1220 µs/cm above the maximum permissible limit. Total dissolved solids (TDS) is an important parameter in drinking water quality standard. It develops a particular taste to the water and at higher concentration reduces its potability water and may cause gastro intestinal irritation with more than 500mg/l. TDS usually have a disagreeably strong taste. High TDS levels generally indicate hard water, which can cause scale build up in pipes, valves and filters. In the present study the value of TDS found in the range 607 to 789 mg/l is above the desirable limit but within the permissible limit as per BIS standard. pH range of 6.5 to 8.5 is normally accepted as suggested by BIS. In this study pH values were found in the range of 7.01to 7.08 in the water samples are within the desirable limit. The total hardness found in the range of 200.7 mg/l to 300.9 mg/l, within the desirable limit as per BIS standard. Calcium hardness found in the range of 72.6 mg/l to 80.7 mg/l sampling of all the locations within the desirable limit as per BIS standard and Magnesium hardness found in the range of 14.8 mg/l to 30.1 mg/l within the desirable limit as per BIS standard. Hardness exceeds the desirable limit, can cause encrustation in water supply structure and adverse effects on domestic use. Alkalinity found in the range of 480.0 mg/l to 610.1mg/l, desirable and permissible limits as per BIS standard. Alkalinity exceeds the desirable limit, can cause taste become unpleasant. Sulphate found in the range of 41.7 mg/l to 63.2 mg/l, within the desirable limit as per BIS standard. Nitrate concentration depends on the activity of nitrifying bacteria which in turn get influenced by presence of dissolved oxygen. In the present study the values of nitrate ranged from 21.3 to 85.4mg/l, exceeds the desirable limit as per BIS standard, can cause Methemoglobinemia or blue baby disease (desirable limit 45 mg/L according to BIS standard). This may be due to the higher phytoplanktonic production, decaying macrophytes and concentration of nutrients owing to the evaporation of lake water with subsequent increase in nitrate value (2). Chloride found in the range of 217.4 mg/l to 201.4 mg/l, within the desirable limit as per BIS standard. Phosphate found in the range of 1.56 mg/l to 6.08 mg/l. Fluoride found in the range of 1.2 mg/l to 1.8 mg/l (1.0gm/l – 1.5 mg/L BIS), exceeds permissible limit as per BIS standard. High fluoride may cause fluorosis. Dissolved oxygen found in the range of 2.4 mg/l to 2.8 mg/l, this can be attributed to addition of effluents containing oxidisable organic matter and consequent biodegradation and decay of vegetation at higher temperature leading to consumption of oxygen from water. Concentration below 5 mg/l may adversely affect the functioning and survival of biological communities and below 2 mg/l may lead to fish mortality. Water without adequate DO may be considered waste water.

Table 1: physico-chemical characters of Varthur lake

Sampling points /Parameters	1	2	3	4	5	6
Temperature, 0^{C}	29.3	29.6	29.4	28.3	28.6	28.1
Colour (Visible)	Greyish black			Dark blue		
Turbidity, NTU	16.2	15.1	14.0	23.4	30.9	25.6
EC, µs/cm	1220	1180	1170	1220	1200	1190

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TDS, mg/l	735	607	732	735	722	789
pH	7.78	7.16	7.01	7.46	7.12	7.26
Total Hardness, mg/l	300.9	276.2	288.4	284.6	292.2	200.7
Calcium mg/l	76.9	56.6	73.8	64.1	80.7	72.6
Magnesium mg/l	30.1	14.8	25.6	29.1	22.3	14.8
Alkalinity, mg/l	550.5	480.0	510.2	610.1	560.8	550.0
Sulphate, mg/l	42.5	56.1	51.2	50.3	41.7	63.2
Nitrate, mg/l	21.3	36.7	79.2	27.9	85.4	24.1
Chloride, mg/l	196.0	181.7	142.5	217.4	201.4	194.5
Phosphate, mg/l	3.12	2.59	6.08	1.56	2.76	3.14
Flouride, mg/l	1.3	1.4	1.6	1.8	1.2	1.4
DO, mg/l	2.8	2.5	2.7	2.8	2.4	2.4
BOD, mg/l	41.8	39.4	55.0	62.0	70.5	69.7
COD, mg/l	121.22	101.41	156.75	155.5	186.82	201.43

The DO values obtained in the present study are less compared to ICMR standards. Biochemical oxygen demand (BOD) found in the range of 41.8 mg/l to 70.05 mg/l, is the measurement of the amount of biologically oxidisable organic matter present in the waste. The increased levels of BOD indicated the nature of chemical pollution. The BOD values obtained in the present study are exceeds the ICMR standards 5.0 mg/l, leads to decreases the level of dissolved oxygen. Chemical oxygen demand (COD) value found in the range of 101.41 mg/L to 201.43 mg/L. COD test which measure the oxygen required for the oxidation of all the substance present in water, included those are not biologically decomposable. COD is a reliable parameter for judging the extent of pollution in water (9).

Conclusion:

The data obtained from the physicochemical parameter analysis of the Varthur Lake clearly indicates all parameters exceeds the permissible level as set by the ISI and WHO. This present situation drastically affects the aquatic and terrestrial ecosystem. To sustain the ecology and aquatic life in the lake, concern authority has to take adequate measures by not allowing the untreated sewage waste and industrial effluent in to the Lake.

References:

1. Sulekh chandra, Arendrasingh and Praveen Kumar Toma., Assessment of Water Quality Values in Porur Lake Chennai, Hussain Sagar Hyderabad and Vihar Lake Mumbai, India: Zakir Husain College (University of Delhi), J.L.N. Marg, New Delhi-110002, India: Chem Sci Trans., 1(3), 508-515, 2012.
2. Preeti Gupta, Sunita Agarwal, and Ira Gupta., Assessment of Physico-Chemical Parameters of Various Lakes of Jaipur, Rajasthan, India; Vedic Kanya PG College, Raja Park, Jaipur, Rajasthan, India: Indian Journal of Fundamental and Applied Life Sciences, Vol. 1 (3), pp. 246 248, July-September, 2011.
3. T. Parameswara Naik, K. V. Ajayan and G. H. Lokesh, Physico-chemical characteristics of Kunigal lake in Tumkur district, Karnataka, India; Int. J. Chem. Sci.: 10(2), 655-663, 2012.
4. Charu Parashar, Savita Dixit and Rajnish Shrivastava1, Seasonal Variations in Physico-chemical Characteristics in Upper Lake of Bhopal, M.P., India; Asian J. Exp. Sci., Vol. 20, No. 2, 297-302, 2006.
5. Trivedi sonal and H. C. Kataria, Physico-Chemical Studies of Water Quality of Shahpura Lake, Bhopal (M.P) with Special Reference to Pollution Effects on Ground Water of its Fringe Areas; Current World Environment Vol. 7(1), 139-144, 2012.
6. Kofo A. Aderogba; Physiochemical Characteristics of Water and Challenges for Community Development; A Case Study of Igbo-Ora Community of Oyo State, Nigeria; International Journal of Basic and Applied Science, Vol 01, No. 01, pp. 129-138, July-2012.
7. Ibandarisuk Lyngdoh and Highland Kayang; Physico-Chemical and Bacteriological Characteristics of Umiam Lake, Meghalaya, India; International Journal of Advanced Life Sciences (IJALS) ISSN 2277 – 758X; IJALS, Vol.3. May – 2012.
8. Ramesh. N and Krishnaiah. S; Scenario of Water Bodies (Lakes) In Urban Areas- A case study on Bellandur Lake of Bangalore Metropolitan city; IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) e-ISSN: 2278-

1684,p-ISSN: 2320-334X, Volume 7, Issue 3, PP 06-14, Jul. - Aug. 2013.www.iosrjournals.org www.iosrjournals.org.

9. 9.Ramesh. N and Krishnaiah. S; Impact on Bangalore Nisarga due to urbanization: Case study of Bangalore city lakes, Karnataka, India; Midas Touch International Journal of Commerce, Management and Technology Volume 2, No. 1, ISSN: 2320 -7787, PP 230-238, January- 2014. www.midastouchjournals.com

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Original Article

Applied Mathematics in Engineering and Applied Sciences

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Abstract

This article presents the role of applied Mathematics in engineering and applied Sciences. Applied Mathematics in Engineering involves using differential equations, linear algebra, calculus and numerical methods. Engineering is the discipline, art and profession of applying Mathematical, Scientific and technical knowledge. In every engineering discipline, mathematics is used to solve problems, design systems, and perform analyses. This Article covers how various areas of mathematics are used in engineering. Some important applications of maths in engineering are Geometry, Differential equation, Linear Algebra, Statistics and Probability, Calculus etc.

Keywords- Applied *Mathematics, Engineering Mathematics, Differential Equations.*

Introduction:

Mathematics is playing an increasingly important role in society and the sciences, enhancing our ability to use models and handle data. Applied mathematics is the application of mathematical methods by different fields such as physics, engineering, medicine, biology, finance, business, computer science, and industry. Thus, applied mathematics is a combination of mathematical science and specialized knowledge. Applied Mathematics in Engineering acts as a bridge between theoretical mathematical concepts and practical real world engineering solutions. It involves application of mathematics in solving many problems of different branches engineering. Like civil, mechanical, aerospace etc.

The Importance of Mathematics in Engineering

Mathematics is the cornerstone of the engineering world. In every engineering discipline, mathematics is used to solve problems, design systems, and perform analyses. From mechanical and electrical engineering to software and civil engineering, professionals rely on mathematical calculations to create safe, efficient, and sustainable solutions.

Let's explore some key reasons why mathematics plays a vital role in engineering:

1. **Mathematics is the language of engineering.** Engineers use math to analyze the durability of structures, the efficiency of circuits, and the accuracy of algorithms. Understanding engineering designs without math is nearly impossible.
2. **As technology advances, the need for mathematics increases.** Fields such as artificial intelligence, machine learning, and automation heavily rely on mathematical models.
3. **Mathematics is essential for innovation.** The development of smart phones, autonomous vehicles, and sustainable energy systems is made possible through complex mathematical computations.
4. **Mathematics is a tool for engineers.** Just as a carpenter needs a ruler for measurements, engineers require mathematics for accurate calculations.
5. **Engineering must minimize errors.** When designing an aircraft or constructing a skyscraper, even the smallest miscalculation can lead to serious consequences.

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6. **Engineering education is based on mathematics.** University engineering programs include calculus, differential equations, linear algebra, and statistics because they are fundamental to advanced engineering topics.
7. **Technology cannot evolve without mathematics.** Computers, AI, robotics, and space exploration all rely on mathematical algorithms to function.
8. **Mathematics is practical, not just theoretical.** Engineers constantly use math to optimize efficiency, calculate error margins, and ensure reliability in their projects.

Importance of applied Mathematics

Mathematics is usually referred to as the universal language of Science and Engineering. Here are few reasons which make maths valuable.

Problem solving – applied Maths is used in a variety of fields to solve complex, real-world issues.

Innovation and technology- applied Mathematics is essential to the operation of many technological innovations, including robots, artificial intelligence.

Data-driven decision making- businesses, healthcare professionals and policy makers use mathematical models to analyse data and make informed choices.

Interdisciplinary applications- There are numerous fields within applied Mathematics. Physics, chemistry, engineering etc. Also, teachers use innovative methods to make maths more fun, which encourages students to develop a deeper interest in the subject.

Some topics of maths which have applications in daily life as follows

Application of Geometry

Geometry is crucial in engineering because it involves shapes, sizes, and spatial relationships. Here are a few examples:

- **Structural Design:** Structural engineers and architects use geometry to design strong and aesthetically pleasing structures. The strength of a structure depends on concepts like center of gravity, load capacity, and stress distribution. The leaning tower of Pisa serves as a reminder of the importance of using math in construction.

  Application of Linear Algebra

  Many areas of engineering use linear algebra, which deals with matrices and vectors.
- **Control Systems:** Electrical engineers use linear algebra to design control systems for robots, aircraft, and other automated machines. These systems require complex calculations to function accurately and consistently. **For example,** linear algebra was used to design the autopilot system in airplanes, which controls the aircraft's flight path automatically.
- **Computer Graphics:** Linear algebra forms the basis for 3D modeling and animation tools used in engineering design and simulation. It helps engineers visualize and analyze complex systems and structures before they are built.

Application of Differential Equations in Engineering

Introduction to Differential equation

Differential equations are a fundamental tool for engineers to model and analyze complex systems. In this article, we will explore the theory of differential equations, and their applications in various engineering fields.

A differential equation is an equation involving an unknown function and its derivative. The unknown function is typically a function of one or more independent variables, and the derivatives are taken with respect to these variables.

The order of a differential equation is the highest order of the derivative that appears in the equation.

For example, the equation $\frac{d^2y}{dx^2}+3\frac{dy}{dx}+2=0$ is a second-order differential equation.

Classification of differential equations

Differential equations can be classified into several types based on their properties. Some of the main classifications are Ordinary differential equations- These are differential equations that involve a function of one independent variable and its derivatives.

Ex- $\frac{dy}{dx}+2=0$

Partial differential equation- These are differential equations that involve a function of multiple independent variables and its partial derivatives.

Ex- $\frac{\partial^2u}{\partial x^2}=\frac{\partial u}{\partial t}$

Differential equations have numerous applications in various engineering fields. Some of the main areas of application are as follows

Mechanical system and vibrations

Mechanical systems are often moduled using differential equations. For example, the motion of a mass-spring-damper system can be moduled using the following second-order ODE

$$m\frac{d^2x}{dt^2}+c\frac{dx}{dt}+kx=0$$

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Where m is the mass, c is damping co efficient and k is the spring constant.
The following table summarizes the types of mechanical systems that can be moduled using differential equations

System	Differential equation
Mass spring damper	$m\frac{d^2x}{dt^2}+c\frac{dx}{dt}+kx=0$
Pendulum	$\frac{d^2\theta}{d\theta^2}+\frac{g}{L}\sin\theta=0$
Forced vibrations	$m\frac{d^2x}{dt^2}+c\frac{dx}{dt}+kx=F0coc(\omega t)$

Electrical circuits and electronics
Electrical circuits can also be moduled using differential equations. For example, the voltage across a capacitor in an RC circuit can be moduled using the following first-order ODE

$RC\frac{dv}{dt}+v=V_{in}$

Where R is the resistance, C is the capacitance, and V_{in} is the input voltage

Fluid dynamics and heat transfer
Fluid dynamics and heat transfer are other areas where differential equations are widely used. For example, the Navier-Stokes equations are a set of nonlinear PDEs that describe the motion of fluids.

$$\frac{\partial u}{\partial t}+u*\Delta u=-\frac{1}{\rho}\Delta p+v\Delta^2 u$$

Where u is the fluid velocity, ρ is the fluid density, p is the pressure, and v is the kinematic viscosity.

Circuit Analysis
Electrical engineers use differential equations to study how electrical circuits behave, including current flow, voltage changes, and power use. This helps engineers build circuits that are reliable and efficient. **For example-** Differential equations are used to calculate the current flowing through a resistor in a circuit.

Heat Transfer Analysis
Mechanical engineers use differential equations to model how heat moves in structures like motors, buildings, and power plants. This helps design systems that maintain the right temperature using less energy.

Application to RLC circuits
The RLC circuit is the electrical circuit consisting of a resistor of resistance R, a coil of inductance L, a capacitor of capacitance C and a voltage source arranged in series. If the charge on the capacitor is Q and the current flowing in the circuit, is I, the voltage across R, L and C are RI, L (dI/ dt) and Q /C respectively.
By the Kirchhoff's law that says that the voltage between any two points has to be independent of the path used to travel between the two points, LI′ (t) + R I(t) + 1 /C Q(t) = V (t)--------(1)
Assuming that R, L, C and V are known, this is still one differential equation in two unknowns, I and Q. However, the two unknowns are related by I(t) = dQ/ dt, so that LQ″(t) + RQ′ (t) + 1 /C Q(t) = V (t) or………2)
Differentiating with respect to t and then substituting dQ/ dt = I(t), LI″(t) + RI′ (t) + 1/ C I(t) = V ′ (t)…………………3)
For an ac voltage source, choosing the origin of time so that V (0) = 0, V (t) = E_0 sin(ωt) and the differential equation becomes LI″(t) + RI′ (t) + 1 C I(t) = ωE_0 cos(ωt) The equations (1), (2) and (3) represents the same system. Also, one can form the equations containing only RL OR only LC circuits.
These are some applications of applied mathematics in engineering.

Similarly, we have applications of mathematics in different fields of science as follows.
In Chemistry
Mathematics is helpful in so many areas of Chemistry like Thermodynamics, stereochemistry in mole fractions, gas equations, quantum chemistry, chemical kinetics, spectroscopy etc. With the help of mathematics all the above topics are easy to understand for students and researchers.

In Physics
Trigonometric Functions: The solution to the SHM differential equation involves trigonometric functions, usually the sine or cosine functions. The general solution for displacement x(t) is x(t)=A cos(ωt+ϕ) Where, A is the amplitude of the motion, ω is the angular frequency, and ϕ is the phase angle.

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Complex Number Representation: SHM can also be described using complex numbers. The displacement x(t) can be expressed as the real part of a complex exponential: x(t)=Re [A ei(ωt+ϕ)] This representation simplifies mathematical manipulations and is particularly useful when dealing with multiple harmonic oscillators.

Vector Representation: Simple harmonic motion can be represented as a vector in the complex plane. The displacement x can be considered as the real part of a complex number z=x+iy, where i is the imaginary unit.

In Computer Science

Computer science is based on math which affects many things that determine how we use technology. This is how math plays a big role in Computer Science.

Cryptography

It is very important to communicate securely in today's digital world. That's where cryptography comes in it uses math to make sure data is kept safe and private. Many cryptography methods are based on difficult math problems like elliptic curve cryptography and integer factorization.

For example, the RSA encryption technique relies on the challenge of factoring large prime numbers, which makes it a common choice for secure communication. Suppose you send a private email. Cryptography which uses Math, scrambles the message so that only people with the right key can read it.

Conclusion

In conclusion, mathematics is an indispensable part of engineering. Mathematics is used in all branches of engineering and has subsequently developed as distinct specialties within the engineering profession. Differential equations are of great importance as almost every area of engineering; almost all real-life situations can be expressed using differential equations. Here I had discussed very few of the applications. I had only constructed the differential equations. The engineering world continuously evolves through the combination of science and mathematics. Without mathematics, progress in engineering would simply not be possible.

References

1. Engineering Mathematics, N.P. Bali, Dr. Manish Goyal
2. Textbook of Engineering Mathematics, Dr. A.B. Mathur, Prof.V.P. Jaggi
3. Ordinary and Partially Differential equations, Dr. M.D. Raisinghania

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Original Article

Advances in Graph Theory and Its Applications

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Abstract

Recent graph theory developments focus on handling very large, complex, and changing data using modern methods and machine learning. Today, graph theory is important in fields like Artificial Intelligence, Bioinformatics, and Cybersecurity, helping to study real-time and complex connections instead of only fixed networks.

Graph theory is a part of discrete mathematics that studies connections between objects using Points and links. In recent years, it has grown rapidly because of advances in computer science, data science, and network technologies. New areas like spectral graph theory, random graphs, efficient graph algorithms, and graph neural networks have increased both its theory and real-world use. This paper reviews these recent developments and shows how graph theory is applied in computer networks, social sciences, biology, artificial intelligence, and operations research.

Keywords*: Graph theory, network analysis, spectral graphs, algorithms applications.*

Introduction:

Graph theory began in 1736 when Leonhard Euler solved the Konigsberg bridge problem. Over time, it has grown into a strong mathematical method for studying complex systems. A graph is made of nodes and links that show how different objects are connected. Today, the rapid increase in data and highly connected systems has made graph models very important. New ideas in both theory and applications of graph theory help solve many real-world problems that involve large and complex networks.

Fundamentals of Graph Theory

The fundamental group of any connected graph Gamma is a free group.

Types of Graphs

1. Simple graphs
2. Directed and undirected graphs
3. Weighted graphs
4. Bipartite graphs
5. Planar graphs
6. Trees and forests
7. These basic structures form the foundationfor advanced graph-theoretic concepts.

Recent Advances in Graph Theory

Spectral Graph Theory

Spectral graph theory studies graphs using eigenvalues and eigenvectors of matrices such as the adjacency matrix and Laplacian matrix.

Random and Probabilistic Graphs

Random graph models, such as the Erodes–Reyna model, help in understanding real-world networks where connections are uncertain. These graphs are used to study:

1. Phase transitions
2 Network resilience
3 Spread of information and diseases

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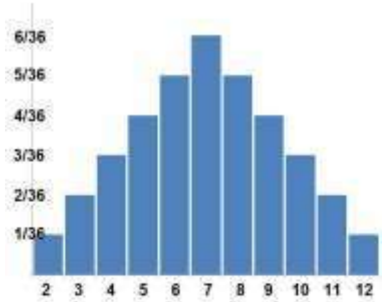
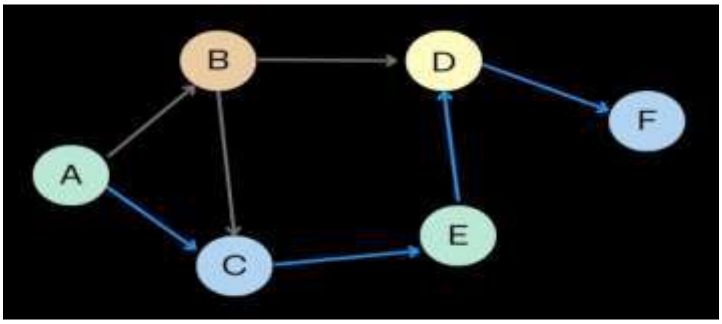


Algorithmic Advances

- Efficient graph algorithms have been developed for:
- Shortest path problems (Digastric, Bellman–Ford)
- Minimum spanning trees (Kreskas, Prim)
- Maximum flow problems (Ford–Fulkerson)
- Recent work focuses on algorithms for large-scale and dynamic graphs.



Graph Colouring and Optimization

Advances in graph colouring help solve scheduling, register allocation, and frequency assignment problems. Approximation and heuristic algorithms are widely used due to computational complexity.

Graph Neural Networks (GNNs)

A major modern advancement is the integration of graph theory with machine learning. GNNs process graph-structured data and are used in:

1. Recommendation system
2. Molecular chemistry
3. Social network analysis

Applications of Graph Theory

1 **Computer Networks and Communication**

Graphs model communication networks, where Vertices represent routers or computers
Edges represent communication links Graph theory helps in network design, routing, and fault tolerance.

2 Social Network Analysis

- Social media platforms use graphs to analyze:
- Friendship relations
- Influence spread
- Community formation

3 Biology and Bioinformatics

- Graphs are used to model:
- Protein–protein interaction networks
- Gene regulatory networks
- Neural networks in the brain

4 Transportation and Logistics

- Graph theory is applied in:
- Route optimization
- Traffic flow analysis
- Airline and railway networks

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5 Operations Research

- Graphs support decision-making in:
- Project scheduling (PERT, CPM)
- Supply chain management
- Resource allocation

Field	Recent Applications and Advances
Machine learnin	Graphs show how users connect, share, and form communities. it studies groups with many connections. Graphs handle data that is not in a straight line. keep the data structure clear even with many dimensions.
Cybersecurity	Graph-based anomaly detection has achieved high accuracy (up to 94.1%) in data to detect network attacks and fraudulent activities by using mathematical patterns.
Biology/Medicine madling	PPI networks: Proteins are shown as points and their interactions as lines. Graphs help study how chemical reactions happen in cells and find problems in metabolism. Graph theory is used to track how diseases spread and to understand links between genes, proteins, and diseases.
Transport	Optimization of traffic flow in “Smart Cities,” fleet management, and calculating shortest paths in GPS systems like Google Maps.
Data Science	Graphs help store and search connected data quickly and easily. Graph theory shows how influence spreads between people in a network.data flow on the internet and find busy or risky paths.
Geomorphology	Graphs measure how complex and stable a landscape is. theory helps track how soil and sand move through river networks. Used to study what areas can be seen from different points

Challenges and Future Directions

- Despite significant progress, challenges remain:
- Handling massive dynamic graphs
- Developing faster algorithms
- Ensuring data privacy in network analysis
- Future research is expected to focus on:
- Quantum graph algorithms
- Integration with artificial intelligence
- Multilayer and temporal graph.

Conclusion

Advances in graph theory have transformed it from a purely theoretical discipline into a vital tool for modern science and technology. Its applications span diverse fields such as computer science, biology, social sciences, and engineering. Continued research in graph theory will further enhance our ability to model, analyse, and optimize complex systems.

Reference:

1. R. Balakrishnan and K. Rangnathan, A text book on Graph Theory, Springer-Berlin
2. R.B. Bepat, Graphs and matrices.

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Original Article

Recent Trends in Computer Technologies

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Abstract

The rapid evolution of computer technology is changing digital ecosystems, business processes, governmental operations, and how humans use computers to perform tasks. This paper is a comprehensive analysis of modern computer technology trends, including advancements in artificial intelligence; cloud computing; edge computing; the internet of things (IoT); 5G networks; blockchain; cybersecurity; quantum computing; emerging technologies such as immersive technologies and robots; big data; and sustainable computing. In this extensive review of how these advances work together to drive digital transformation, this paper synthesizes current research from academic literature with real-world applications of computer technologies from industry.

The paper includes discussions regarding the emergence of generative AI and multimodal ML methods, explainable AI, and intelligent automation as new methods to generate better decision-making results and innovations within the business sector. It includes descriptions of multi-cloud/hybrid architectures, serverless computing, edge AI, and fog computing as ways to achieve low-latency scalable infrastructure; and ultimately describes use cases for using IoT with AI-enabled analytic platforms for smart cities; IIoT; and real-time data ecosystems. Cybersecurity subjects discussed in this paper include innovations such as Zero Trust Architecture, AI-based threat detection, and quantum-resistant cryptography.

Emerging technology paradigms like blockchain-powered decentralized apps (DApps), Web3 environments, quantum algorithms, AR/VR/MR technologies, and smart robots are examined for potential to change organisations and challenges encountered during their adoption. 'Green computing' strategies are discussed in terms of developing low carbon power systems, creating carbon aware IT systems, and developing sustainable IT practices that reduce environmental impact.

This study also explores advances in the fields of human computer interaction, accessibility technology, and ethical governance frameworks, with a focus on society's responsibility to develop inclusive and responsible technological products.

The research has revealed multiple challenges that prevent sustainable technology development from progressing, including: scalability; interoperability; regulatory compliance; security threats; digital equity; and adapting to the workforce's new skill sets caused by this shift to sustainable technology. Therefore, developing sustainable technology will require multi-disciplinary co-operation; ethical guidance/path; strategic governance; and continuous innovation in technology development. By combining a technical assessment of IT technology along with a social perspective; an umbrella of knowledge will form to forecast how IT technologies will advance during the period referred to as the era of Intelligent Connected Systems.

Keywords: *Artificial Intelligence (AI); Machine Learning (ML); Generative AI; Cloud Computing; Edge Computing; Internet of Things (IoT); 5G and Next-Generation Networks; Blockchain; Web3; Cybersecurity; Quantum Computing; Extended Reality (AR/VR/MR); Robotics and Intelligent Automation; Big Data Analytics; Green Computing; Sustainable IT; Human–Computer Interaction (HCI); Digital Transformation; Zero Trust Architecture; Ethical AI.*

Introduction:

The 21st century's rise of computer technologies changed economies, how we discover science and societal norms.

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The computing and computer-based management systems create the platform for almost all industries in the world, i.e. banking, healthcare, education, manufacturing, transportation and government. They all utilize computer technology to automate their industrial functions and perform instantaneous global communications.

As digital technologies become standard in all aspects of life, traditional operations are evolving from linear operation processes to intelligent, automated operations that have the ability to learn and change based on input data; develop and create predictions using data; and independently make decisions regarding their operations.

The transition from traditional computing models to modern intelligent computing systems marks a major shift in the technology paradigm from traditional computing models to modern intelligent computing models, from processing logically structured relationships and deterministic behaviours to systems that have AI and ML, and which can operate using pattern recognition; understand language using natural languages; see using computer vision; and reason using high-level logic. With these technologies, companies will be able to use the technologies to automate routine tasks and provide strategic decision making and personal services at scale.

The transformation of Cloud Computing has changed the way that companies manage their infrastructures by providing them access to scalable, on-demand resources across a centralised (or distributed) computing network. More and more organisations are using hybrid and multi-cloud environments to create flexible, cost-effective and resilient IT services.

With the growth of the Internet of Things (IoT) and billions of smart devices and sensors being interconnected, the interconnected systems of the IoT are generating vast amounts of data which require the use of advanced analytics tools, secure communications frameworks and robust cybersecurity mechanisms. With an increasing reliance on digital services, cybersecurity is now seen as a strategic priority, with focus on threat detection, data protection and the design of resilient systems.

At the same time, Quantum Computing is emerging as an area of significant potential to solve complex problems (i.e., problems involving optimisation, cryptographic or simulation capabilities) in ways that existing classical computing systems cannot. Quantum technologies are still being developed, but will likely have a transformative impact on the fields of scientific research, artificial intelligence and secure communications.

The present research effort, which compiles recent research articles from both the academic community and the industry, looks at current trends in computer technology. The paper looks into the technical underpinnings of the technologies, their applications to practice, their impact on society, and their potential future trends. The research article integrates both the technology and its ethical, legal, and economic issues to provide an overall view of how the new computing technologies are changing the global digital landscape, as well as the ways in which the relationship between people and intelligent systems is being altered.

Key Trends in Computer Technologies

The rapid transformation of the landscape of computer technologies is a result of advances in computational power, data availability, connectivity, and intelligent algorithms. Emerging technologies have begun to converge as opposed to developing separately; it is now common for them to create integrated, adaptive and intelligent digital ecosystems. This subsection will explore the major trends that are shaping the future of computing and will discuss their technical foundations, applications, and larger implications.

1 Artificial Intelligence (AI) and Machine Learning

AI Continues to Be the Most Disruptive Force in Contemporary Computing due to Advances in Machine Learning, Deep Learning and Generative Models Giving Rise to New Standards of Performance within Nlp, Computer Vision, Speech Recognition & Predictive Analytics. LLMs Will Allow Machines to Understand/Generate Text and Other Forms (Image/Audio/Video) With Increased Precision Than Ever Before.

Enterprise Applications Using Cloud Services, Health Care Diagnostics, Self-Driving Cars, Robotics, And Finance Are All Taking Advantage of AI Technologies By Creatively Automating Business Processes and Augmenting Customer Experience, Supply Chain Optimization, & Supporting Strategic Planning Using Data-Driven Insights. As Organizations Use More Artificial Intelligence Technologies, Ethical Principles Associated with The Deployment of Responsible AI, Such Like Fairness, Transparency, Explainability (XAI), & Accountability, Have Not Only Become More Critical for Conducting Ethical Deployments but Also for Minimizing Biases to Which Algorithms May Be Subjected.

2. Cloud Computing and Distributed Architectures

Digital infrastructure is now heavily dependent on cloud computing. The modern cloud infrastructure offers a wide variety of services that include flexible, high-performance computing; scalable, high-speed storage; the ability to use artificial intelligence; and a global delivery network for all the content that is created or delivered via the Internet. Additionally, serverless computing, microservice architecture, containerization, and orchestration using Kubernetes have revolutionized the deployment of applications by providing a more flexible and robust way to deploy applications. Employing hybrid and multi-cloud strategies allows organizations to distribute workloads across both public and private environments to provide cost and performance efficiencies and comply with regulatory duties. The convergence

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of AI and cloud computing commonly called AI-as-a-Service accelerates innovation through the use of machine learning tools and infrastructure easily available to all companies.

3 Internet of Things (IoT) and Edge Computing

With the Internet of Things connecting many devices, sensors, and smart systems, the amount of real-time data generated by these interconnected devices has increased dramatically. Examples of how IoT applications are being used include: smart cities; industrial automation (IIoT); healthcare monitoring; environmental tracking; and smart homes.

By performing processing at the edge of a network, edge computing improves the performance of IoT systems by reducing both latency and bandwidth requirements. With edge AI, ML models used to analyze data can be processed directly by devices instead of always relying on access to a cloud service. This distributed intelligence architecture is especially beneficial for systems requiring fast feedback loops, such as autonomous vehicles or industrial robots.

4 Cybersecurity and Privacy Protection

With the growth of digital ecosystems, cybersecurity is now a significant concern. The growing interconnectivity between cloud systems, Internet of Things (IoT) devices, and enterprise networks creates a larger attack surface than previously existed. As such, the design of today's cybersecurity strategies utilizes a more proactive and adaptive approach to defense.

There are many innovative developments that support proactive cybersecurity strategies today. Among them are Zero Trust Architecture (ZTA), Artificial Intelligence (AI)-(driven) threat detection systems, identity and access management (IAM), behavioral analytics, and post-quantum (PQ) cryptography. Other recent developments include privacy-preserving technologies such as homomorphic encryption and federated learning, both of which allow organizations to collaborate in analyzing sensitive information while preserving the privacy of that data.

5 Quantum Computing

Quantum computing changes how computers work; it's a complete game-changer! You can now run multiple calculations simultaneously using qubits (quantum bits) because they take advantage of superposition and entanglement. Therefore, there are many types of difficult optimizations, cryptography, and simulations that classical computers would struggle to accomplish.

Many governments and tech companies have invested millions in quantum computing research, therefore furthering the advancement of quantum algorithms into practical quantum technology. There is also a movement towards cloud-based quantum computing platforms where researchers and developers can experiment with quantum algorithms.

6 5G and Next-Generation Networking

The implementation of fifth-generation (5G) wireless technologies is an important advancement in communication infrastructure. 5G provides ultra-high data rates, provides network capacity to connect many devices, and allows for ultra-low latency communications. These features are necessary to support real-time applications such as self-driving cars, remote doctor surgeries, automated factories (industrial automation), and smart cities.

Research is continuing into sixth-generation (6G) networks where methods used to join two systems as well as new telecommunications technologies such as terahertz communication, artificial intelligence (AI) native network management, holographic communications, and integrated sensing will be utilized. An operator can use "network slicing" to create virtualized applications based on the application such as healthcare, manufacturing, or entertainment by using different (unique) network segments. Optimizing the network with artificial intelligence will support efficient traffic management, predictive maintenance, and quality of service assurance.

7 Blockchain & Web3

The introduction of blockchain technology gives us decentralized and immutable digital ledgers, which improve transparency, confidence & data integrity for all types of digital transactions. Although it was first marketed under the concept of cryptocurrency (i.e., Bitcoin), there are many other potential application areas for blockchain including but not limited to supply chains, digital identity management, medical records and financial services.

As we move into the Web3 world with decentralized architecture, users will have more control over data and digital assets they previously could not have possessed. Smart contracts provide automated trust without having to use any middlemen/third parties; decentralized applications (DApps) do run off distributed computing networks (blockchains). That said, there are still substantial challenges that exist today around scalability, energy consumption, interoperability and regulation before we will see wide-spread adoption of blockchain-related technologies globally.

8 Extended Reality (AR/VR/MR) and the Metaverse

Extended Reality (XR) encompasses a variety of immersive computing environments, including Augmented Reality (AR), Virtual Reality (VR), and Mixed Reality (MR), which create new types of interaction with the digital world and allow for more engaging user experiences through visualization, simulation, and interactivity in real time.

The applications for XR are broad and include everything from training simulations in healthcare to remote collaboration, immersive education, virtual prototyping, and pure entertainment. The Metaverse describes a set of interconnected, persistent virtual environments in which users can socially and economically interact with each other.

The continued advancement of tools and platforms such as advanced wearable hardware, spatial computing, and graphics processing accelerates XR adoption, but there remain significant barriers such as accessibility issues, privacy-related concerns, and high costs associated with hardware.

9 Green Computing and Sustainable IT

Digital infrastructure is growing rapidly, and energy use and environmental impact are growing important issues. Green Computing is the concept of designing systems to use less energy, creating data centres that are sustainable, and creating electronic equipment in an environmentally friendly manner.

English companies are working on a range of innovations, including: Carbon-Aware Cloud Computing, Data Centres powered by Renewable Energy, Advanced Liquid Cooling Technologies, and Workload Optimisation Scheduling.

Sustainable IT practices address electronic waste (E-Waste), hardware recycling and hardware lifecycle optimisation. AI will help improve energy efficiency during the digital transformation from paper to digital.

10 Robotics and Intelligent Automation

The merger of technology includes artificial intelligence (AI), computer vision, and sensor technologies—these three technologies are providing new ways to enable intelligent automation and robotics. Robotic Process Automation (RPA) automates repetitive digital functions that exist in business, allowing for improved efficiencies and reduced operational costs.

Autonomous systems like delivery drones, warehouse robots, and driverless vehicles are transforming logistics, manufacturing, and transportation. Human-robot collaboration (cobots) improves productivity by allowing for safe interaction between humans and robots within a shared environment. AI-based robotic technology is evolving towards adaptive learning and contextual decision-making capabilities as it advances.

11 Big Data and Advanced Analytics

Big data analysis has become increasingly important due to the exponential growth of data generated by many digital platforms, IoT devices, and enterprise systems. Modern computing frameworks allow for real-time processing of data, predictive modeling, and advanced forms of analytics, by way of both distributed systems and through the cloud. Data lakes and lake-house architectures allow for the scalable storage of large amounts of data while providing a unified analytics environment to analyse all collected data. Predictive and prescriptive analytics will help organizations forecast trends, improve operations, and provide better strategic planning. However, effective data governance, quality management and regulatory compliance will continue to be essential in order to generate meaningful and ethical insights from data analytics.

12 Human–Computer Interaction (HCI)

The study of Human-Computer Interaction (HCI) aims to enhance how easily people can use and access computer systems and how naturally people can interact with them. New technologies, like voice-controlled devices and gesture-based devices, as well as the continued development of conversational agents and smart interfaces, will provide users with new ways of interacting with digital systems.

Developments in innovative technologies such as brain-computer interface (BCI) devices and emotion-aware systems will improve communication between humans and machines directly. Technologies designed to provide access for people with disabilities allow for equitable participation in digital ecosystems; as interface technology continues to become more immersive and intelligent, user design principles will remain an essential component of user-centered design.

13 Ethical, Legal, and Social Implications

The fast pace at which innovative computer technology is being applied creates major ethical, legal and societal issues. These include concerns related to data privacy; algorithmic bias; misinformation; surveillance; and digital inequality and require oversight and governance to ensure responsible use. The Framework for the Governance of AI emphasizes transparency, fairness, accountability, and explainability of the technology; while Regulations for the Protection of Personal Data aim to protect individuals' data while allowing for innovation and new uses of technology. In the case of transforming the workforce as a result of automation, using these technologies such as AI will require reskilling workers and policies that allow for the adaptation of individuals to prevent economic disruptions from occurring. Therefore, safe and responsible progress in technology requires the balancing between innovation and the ethical standards, public confidence in the technology, and equal access to the digital world.

Applications And Impacts

1 Industry and Business Transformation

The increasing reliance on cloud-based infrastructure, AI analytics and intelligent automation to enhance competitiveness and optimize enterprise performance has profoundly transformed modern business operations. Machine learning is used to analyze data from multiple sources (big) to determine how and when to purchase and operate goods (predict) and provide support for strategic decision-making.

Manufacturers can also use IIoT technology to better manage their factories through predictive maintenance by reducing unplanned downtime (failure) of equipment and lowering material costs (material). Real-time tracking through IIoT technology (sensors) provides transparency throughout the supply chain and enables the use of AI to optimize operations. In finance, AI-based fraud detection systems, automated trading strategies and personalized banking services are helping financial institutions reduce costs and build customer loyalty.

Cloud computing allows businesses to rapidly implement new innovative ideas. Businesses can scale (automatically adjust), deploy (continue to grow) globally to meet demand, and utilize AI as a service (reduce cost) without having to invest heavily in infrastructure. Therefore, organizations can adapt or respond more quickly to competitive pressure and digital disruption.

2 Healthcare and Life Sciences

Healthcare delivery and medical research have been greatly improved by recent advancements in computer technology. AI diagnostic tools have helped clinicians analyze medical pictures with greater accuracy, allowing for earlier diagnosis, as well as providing recommendations for personalized treatment plans. Predictive analytics is used to identify patients at a higher risk to receive preventive care.

Wearable devices (i.e. accessories that connect to the internet) help provide remote monitoring of patients, manage chronic diseases, and track daily health metrics in real time. Cloud-based systems of health information enable medical users to share patient information securely, allowing for better coordination of care as well as continuity of care. Quantum computing and high-performance computing are being investigated to simulate complex molecular interactions and assist with drug discovery. These innovations will enhance precision medicine by improving research capabilities and improving patient care/effectiveness.

3. Education and Digital Learning

Education has undergone a major change due to AI and cloud computing technology. Intelligent tutor/teaching tools and adaptive learning platforms help customize student learning through performance and learning methods; as well as providing teachers with automated grading and analytics to track student progress.

Cloud infrastructure has allowed for remote/hybrid learning with collaboration through digital content delivery; classrooms; and virtual classrooms. Immersive degrees of learning using extended reality (AR/VR) can be developed in areas such as science, engineering, or medical education. All of these developments will open doors to education; provide worldwide educational opportunities and help promote digital literacy. However, achieving equity in technology access is still a major barrier to bridging the digital divide.

4 Smart Cities and Public Services

Improve urban management and sustainablity by employing IoT sensors, Data Anylitics and AI systems through smart city initiatives. Some examples of how this is done are with intelligent traffic control; smart energy grid infrastructure, optimised waste management and environmental monitoring.

With 5G networks creating a more extensive connection for autonomous vehicles, emergency response and real-time surveillance. Data-driven public administration allows public administrators to make better policy decisions and provide better services to citizens. Smart Cities seek to better quality of life overall; lessen the impact on the environment; and create a sustainable urban development model through tech/infrastructure integration.

5 Environmental Sustainability

Green Computing efforts help to reduce Digital Infrastructure's Environmental Footprint through AI-powered Energy Optimization for Data Centers & Smart Grids. Many Cloud Providers now use Renewable Energy sources to operate large-scale data centers.

Advanced analytics can be used in Climate Models, Environmental Monitoring, and Resource Management. IoT Sensors can provide real-time Information on Pollution Concentration/Pollution Levels; Water Quality; Agricultural Conditions, enabling Sustainable Decision-making. All these Technologies show how Computing Innovations can support Global Sustainable Goals while supporting Economic Growth and Environmental Responsibility.

6 Societal and Economic Impact

Emerging computer technologies have already had a large societal impact; their broad acceptance is evidenced by the introduction of automated systems that improve productivity while changing many aspects of the economy and the workplace. Automation will result in new labor markets and change existing ones, thus necessitating reskilling and adaptability of workers.

Emerging digital platforms will improve individual access to commerce, communication, and governance and will further improve economic access; however, there are some key areas of concern regarding the applicability and need for ethical governance and regulation due to the potential for infringements on privacy, cybersecurity, misinformation, and/or algorithmic bias. It is imperative to develop inclusive technology and promote digital literacy programs to ensure equitable access to technology and to minimize socioeconomic disparities.

Challenges And Ethical Considerations

1 Privacy and Security

The rapid growth of data created by AI systems, IoT devices, cloud platforms, and digital services has raised serious concerns about privacy and cybersecurity. Collecting large amounts of data increases the risk of breaches,

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identity theft, ransomware attacks, and cyber espionage. As systems connect with each other more, the chances of attacks increase, making strong security measures essential.

New technologies like Zero Trust Architecture, encryption standards, federated learning, and post-quantum cryptography aim to improve data protection. However, keeping sensitive information safe while ensuring usability and innovation is a tough challenge. It requires ongoing monitoring, flexible security models, and global cooperation.

2 Ethical Algorithms and Responsible AI

Artificial intelligence systems have a big impact on decision-making in finance, healthcare, recruitment, law enforcement, and governance. Biased datasets, unclear model structures, and a lack of explainability can result in unfair outcomes. It is crucial to ensure fairness, transparency, accountability, and explainability in algorithms.

Explainable AI (XAI) frameworks, bias detection tools, and ethical auditing methods are being used more often to support responsible use. Organizations need to include ethical design principles from the beginning. This way, AI systems can respect human rights, inclusivity, and societal values.

3 Workforce Transformation and Skill Gaps

Automation and intelligent systems are changing labor markets. New technologies create opportunities in AI development, cybersecurity, cloud engineering, and data science. However, they also replace routine and repetitive tasks. This change needs ongoing workforce reskilling and adjustment. Educational institutions, governments, and industries should work together to create digital literacy programs, technical training initiatives, and interdisciplinary curricula. Closing the skill gap is essential for keeping economic competitiveness and ensuring fair participation in the digital economy.

4. Governance and Regulatory Alignment

The fast growth of technology often outpaces rules and regulations. Policymakers must find a way to balance innovation with public safety, privacy, and ethical responsibility. Issues like cross-border data flows, AI governance standards, digital monopolies, and cybersecurity rules need global strategies that work together.

Good governance requires teamwork among governments, tech companies, universities, and the public. Flexible regulatory models that change as technology develops are crucial for building trust and ensuring long-term sustainability.

Future Prospects

The future of computer technology will involve strong technological convergence and smart integration. AI-native computing architectures are expected to put machine learning capabilities directly into hardware and software systems. This will create platforms that can adapt and optimize themselves.

Cloud computing will more frequently include quantum processing units (QPUs). This will lead to hybrid classical-quantum cloud environments that can handle complex optimization and simulation problems. Edge computing will grow to support autonomous systems that operate with minimal delays, especially in transportation, healthcare, and smart infrastructure. Improvements in 6G networking, immersive computing, human-machine interfaces, and sustainable IT practices will speed up digital transformation. New decentralized systems, privacy-focused computation, and carbon-aware infrastructures will change operational models in various industries.

In the next decade, industries are likely to see:

- Intelligent, autonomous enterprise ecosystems
- Real-time global connectivity with ultra-low latency
- Quantum-enhanced scientific research and secure communications
- Fully integrated smart cities and digital healthcare systems

These developments suggest a future where computing systems are more adaptable, secure, energy-efficient, and centered around human needs.

Conclusion

Recent trends in computer technologies are changing the tech landscape and altering societal structures. The merging of artificial intelligence, cloud and edge systems, IoT ecosystems, cybersecurity advancements, quantum computing, and sustainable IT is causing significant changes across industries and public sectors. While these developments offer major chances for efficiency, innovation, and a better quality of life, they also bring complex issues regarding ethics, privacy, workforce changes, and governance. Using new technologies responsibly requires a balanced approach that combines technical skill with ethical oversight, regulatory support, and ongoing education.

In the end, the future of computing will rely not just on technological breakthroughs but also on our ability to steer innovation toward inclusive, secure, and sustainable progress. By promoting teamwork across different fields and responsible innovation practices, society can fully harness the benefits of modern computer technologies for long-term global gain.

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Reference

1. M. Sharjeel, S. Tariq, M. Ahmad, A. Aslam, et al., "An interdisciplinary review of modern computer science: Trends and challenges in AI, cybersecurity, cloud, blockchain, IoT, data science, NLP, vision, software engineering, and quantum computing," *Scholars Journal of Engineering & Technology*, 2025.
2. J. Wu, J. Liu, Y. Liu, L. Wang, et al., "A survey on cloud-edge-terminal collaborative intelligence in AIoT networks," *arXiv preprint*, 2025. [Online]. Available: https://arxiv.org
3. S. S. Gill, M. Golec, J. Hu, M. Xu, et al., "Edge AI: A taxonomy, systematic review and future directions," *arXiv preprint*, 2024. [Online]. Available: https://arxiv.org
4. M. S. Hossain et al., "Quantum-edge cloud computing: A future paradigm for IoT applications," *arXiv preprint*, 2024. [Online]. Available: https://arxiv.org
5. A. Prangon and J. Wu, "AI and computing horizons: Cloud and edge in the modern era," *Journal of Sensors and Actuator Networks*, 2024. [Online]. Available: https://www.mdpi.com/journal/jsan
6. M. I. Khan, A. Arif, and A. R. Khan, "The most recent advances and uses of AI in cybersecurity," *BULLET: Jurnal Multidisiplin Ilmu*, 2025.
7. K. Razzaq and M. Shah, "Advancing cybersecurity through machine learning: A scientometric analysis of global research trends," *Journal of Cybersecurity & Privacy*, 2025. [Online]. Available: https://www.mdpi.com/journal/jcp
8.] F. Li and C. Wang, "Artificial intelligence and edge computing for teaching quality evaluation based on 5G," *Journal of Cloud Computing*, 2023. [Online]. Available: https://journalofcloudcomputing.springeropen.com
9. V. R. Keesara, "The next frontier: Emerging trends in cloud computing and digital innovation," *International Journal of Computer Engineering & Technology (IJCET)*, 2025.
10. L. Tamrakar, "Recent trends in computer technology: AI, cloud computing, quantum computing, and cybersecurity," *Journal of Computational Analysis and Applications*, 2023.
11. A. Tiwari and M. Darbari, Eds., *Emerging Trends in Computer Science and Its Application*. Boca Raton, FL, USA: CRC Press, 2025. [Online]. Available: https://www.routledge.com
12. A. K. Singh, Z. A. Siddiqui, et al., Eds., *Recent Advances in Computational Intelligence and Cyber Security*. Boca Raton, FL, USA: CRC Press, 2025. [Online]. Available: https://www.routledge.com
13. "Internet of intelligent things: A convergence of embedded systems, edge computing & machine learning," *Internet of Things Journal*, 2024. [Online]. Available: https://www.sciencedirect.com

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Original Article

Future of Computing: - Trends and Challenges

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Abstract

The field of computer technologies is evolving rapidly, driven by demands for higher performance, enhanced connectivity, and intelligent automation. Recent trends include advancements in artificial intelligence (AI) and machine learning (ML), edge computing, quantum computing, cybersecurity innovations, Internet of Things (IoT) expansion, and development in human-computer interaction (HCI). This paper examines these key trends, explores their applications, discusses challenges, and suggests future directions. Understanding these technological trajectories is essential for researchers, industry professionals, and policymakers aiming to shape the next era of computing innovations.

Keywords*: Artificial Intelligence (AI), Cloud Computing, Cybersecurity, Technology Adoption Trends, Digital Transformation.*

Introduction:

Recent advancements in computer technology have transformed nearly every aspect of modern life, including healthcare, education, business and entertainment. Emerging technologies such as artificial intelligence (AI), cloud computing, quantum computing and cybersecurity are driving rapid innovations across industries. AI and machine learning help organizations analyse large amounts of data, improve decision-making and automate complex tasks. Cloud computing provides scalable and flexible solutions that enhance collaborations and efficiency. At the same time, quantum computing is emerging as a powerful technology capable of solving complex problems beyond traditional systems. These advancements are making digital smarter, faster and more connected. However, increased connectivity also brings cybersecurity challenges that require strong protection of data and system. Organizations must adopt modern security measures to maintain privacy and reliability. Recent trends in computing focus on innovations, automation and digital transformation. This introduction highlights the importance of understanding technological developments and their impact on future computing and society.

Literature Review

Researchers have analysed recent developments in computing from multiple perspectives

Ai And Machine Learning

AI and machine learning remain at the forefront of technological innovations as role in enhancing business processes predictive analytics and automation is expanding rapidly according to a Mckinsey report (2023), over 50 % of businesses are using AI to improve customer service and decision making. Recent trends include the development of transfer models (e.g. in language tasks) explainable AI and AI ethics frameworks to ensure responsible deployment.

Edge And Cloud Computing

Cloud Computing continues to revolutionize how organisation store access and manage data providing scalability and cost efficiency.

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It shows a shift towards decentralized computing to reduce latency and bandwidth use.

Quantum Computing
Though in its infancy, Quantum computing promises to solve problems beyond the capabilities

Key Trends in Computing
- Quantum Computing: Shifting from binary bits (0s and 1s) to qubits allows for parallel processing at an unimaginable scale. While currently experimental, it is expected to be accessible via the cloud by 2050 to solve the world's most complex problems.
- Edge and Fog Computing: To reduce latency, computing is moving closer to the data source (the "edge") rather than relying solely on centralized Cloud Computing.
- Artificial Intelligence (AI) Everywhere: AI is being integrated into every layer of computing, from smarter, intuitive applications to autonomic computing that can manage and repair itself without human intervention.
- Neuromorphic and Biologically-Inspired Computing: Developing hardware that mimics the human brain's neural structure to improve energy efficiency and cognitive processing.
- Ubiquitous Computing: The rise of Internet of Things (IoT) and sensor networks is making computing invisible and omnipresent in daily life, from smart cities to wearable health monitors.

Cybersecurity Innovations
As computing grows more complex, so do cyber threats. Modern cyber security focuses on adaptive AI-powered differences and secure system design.
Current trends:
- Zero-trust architecture
- AI/ML for threat detection
- Secure multi-party computation for privacy
- Block chain for data integrity

These trends address threats ranging from ransomware to supply chain attacks.

Cybersecurity Attack (2021-2023):
Cybersecurity solutions including AI-driven threat detection, encryption and multi-factor authentication, are becoming essential as companies manage more sensitive data online. Overall, the 2021-2023 period highlights that cybersecurity is not just a technical issue but a global security and economic concern. Organizations must adopt proactive security measures, continuous monitoring and awareness training to combat evolving cyber threats.

Human-Computer Interaction (Hci)
HCI aims to make computing systems more intuitive and seamless for users.
Recent developments include:
- Gesture and voice-controlled interfaces
- Augmented reality (AR) overlays
- Brain-computer interfaces (BCI) in research
  The goal of these innovations is to make interactions between users and computers more natural and accessible.
- Critical Challenges
- Security and Privacy: As data moves across more devices and borders, Data Sovereignty and compliance with regulations like GDPR or HIPAA become increasingly difficult to maintain.
- Energy Consumption and Sustainability: Data centers and advanced AI training require enormous amounts of power, leading to significant heat dissipation and environmental concerns.
- Moore's Law Limitations: Traditional hardware is reaching its physical limits in terms of transistor density, requiring a shift toward novel materials and architectures.
- Interoperability and Vendor Lock-in: Organizations face high costs and technical hurdles when trying to move data or applications between different cloud providers.
- Complexity of Big Data: The "digital universe" is expanding exponentially, making it harder to extract meaningful insights without overwhelming existing storage and analysis tools.

Future Directions
Emerging areas likely to shape the next decade include:

I. **Neuromorphic computing**: It is a brain-inspired approach to hardware and software design that mimics the neural structure of the human brain to create highly efficient, fast, and adaptable AI systems. Unlike traditional computers, these systems use spiking neural networks (SNNs) to process information asynchronously, consuming less power while allowing for on-chip learning, real-time sensory processing, and parallel computation.

II. **AI democratization**: It is the process of making artificial intelligence technologies, tools, and capabilities accessible to a broad, non-technical audience rather than just specialized experts. By utilizing open-source

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frameworks, low-code/no-code platforms, and cloud-based AI, it aims to lower entry barriers, foster innovation, and distribute the economic benefits of AI across society, rather than concentrating them in a few tech firms.

III. **Sustainable computing**: Sustainable computing (or green IT) minimizes the environmental impact of technology across its entire lifecycle—design, manufacturing, usage, and disposal—to reduce carbon emissions, energy consumption, and electronic waste. Key strategies include using energy-efficient hardware, optimizing software, utilizing renewable energy in data canters, and promoting a circular economy through repair and recycling.

IV. **Integration of AR/VR in education and remote work:** AR/VR technology is transforming education and remote work by enabling immersive, interactive, and spatial experiences that boost engagement, knowledge retention, and collaboration. Key applications include 3D simulations for complex subjects, virtual field trips and remote collaborative 3D workspaces. Despite challenges like high costs and infrastructure needs, AR/VR improves learning outcomes and productivity.

Conclusion

In conclusion, researching the recent trends in computer technology has shown that we are living through one of the most exciting shifts in the history of the field. What used to be "futuristic" concepts—like Artificial Intelligence that acts on its own or Quantum computers solving real-world problems—are now becoming part of our daily reality.
Throughout this paper, it has become clear that technology is no longer just about making faster hardware. Instead, the focus has shifted toward integration and intelligence. We are seeing a move away from simple automation toward "Agentic AI," where systems can reason and make decisions. At the same time, the rise of Edge Computing is bringing more power to our local devices, while Cybersecurity is evolving to protect us against increasingly sophisticated digital threats.

It is evident that staying updated is no longer optional; it is a necessity. While the speed of these changes can be overwhelming, they also offer incredible opportunities to solve global challenges in health, environment, and communication. The future of computing will not just be defined by the code we write, but by how ethically and sustainably we deploy these powerful tools to improve human life.

References

1. McKinsey & Company. (2023). *The State of AI in 2023: Generative AI's Breakout Year*. McKinsey Global Survey Report.
2. IBM. (2023). *What is Quantum Computing?* IBM Research. Retrieved from https://www.ibm.com/quantum-computing/
3. National Institute of Standards and Technology (NIST). (2022). *Zero Trust Architecture (SP 800-207)*.
4. World Economic Forum. (2023). *Global Cybersecurity Outlook 2023*.
5. Gartner. (2023). *Top Strategic Technology Trends 2023*.
6. Microsoft. (2023). *Cloud Computing and Edge Innovation Report*.
7. European Parliament. (2016). *General Data Protection Regulation (GDPR)*.
8. U.S. Department of Health & Human Services. (1996). *Health Insurance Portability and Accountability Act (HIPAA)*.
9. MIT Technology Review. (2023). *10 Breakthrough Technologies*.
10. Stanford University. (2023). *AI Index Report 2023*.