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CONTENTS

Preserving the Pulse of the Western Ghats: Strategies for Biodiversity Conservation in a Climate-Stressed Landscape

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Abstract
The Western Ghats, a UNESCO World Heritage site and one of the world's eight "hottest hotspots" of biological diversity, are facing unprecedented ecological stress due to climate change, land-use transformation, and anthropogenic pressures. This paper explores the multifaceted challenges threatening the region's rich biodiversity and proposes integrative conservation strategies tailored to its unique ecological and socio-cultural context. Drawing on recent climate models, biodiversity assessments, and field studies, the research highlights how rising temperatures, erratic rainfall patterns, and habitat fragmentation are altering species distribution and ecosystem dynamics. Special attention is given to endemic flora and fauna, whose survival is increasingly jeopardized by shrinking habitats and invasive species.

The study advocates for a landscape-level conservation approach that combines protected area expansion, ecological corridor development, and community-led stewardship. It also emphasizes the role of indigenous knowledge systems and participatory governance in enhancing ecological resilience. Case studies from Kerala, Karnataka, and Maharashtra illustrate successful interventions such as sacred grove preservation, agroforestry adoption, and decentralized water management. By integrating scientific insights with traditional practices, the paper argues for a more inclusive and adaptive conservation framework.

Ultimately, this research underscores the urgency of preserving the ecological pulse of the Western Ghats—not only for regional sustainability but also for global biodiversity heritage. The findings aim to inform policymakers, conservationists, and local communities in crafting strategies that are ecologically sound, culturally respectful, and climate-resilient.

Keywords - Western Ghats, Biodiversity Conservation, Climate Change, Habitat Fragmentation, Endemic Species, Ecological Resilience

Introduction

The Western Ghats, a chain extending along the western coast of peninsular India, represent one of the most ecologically significant and biologically diverse regions globally. Designated as a UNESCO World Heritage site, the Ghats are recognized for their exceptional levels of endemism and species richness, encompassing over 7,400 species of flowering plants, 139 mammal species, and 179 amphibians. Functioning as a critical ecological corridor, the region plays a pivotal role in regulating monsoonal dynamics, maintaining hydrological cycles, and supporting agro ecosystems and forest-based livelihoods across six Indian states.

Despite their ecological prominence, the Western Ghats are increasingly threatened by anthropogenic pressures and climate-induced stressors. Rapid land-use changes—driven by urban expansion, agricultural intensification, mining, and infrastructure development—have led to habitat fragmentation, soil degradation, and biodiversity loss. These transformations are particularly detrimental to endemic and specialist species, which are often confined to narrow ecological niches. Concurrently, climate variability, characterized by rising temperatures, altered precipitation regimes, and increased frequency of extreme weather events, is exacerbating ecological instability and challenging the adaptive capacity of both species and ecosystems.

The compounded impact of these stressors necessitates a re-evaluation of existing conservation paradigms. This study investigates the intersection of climate stress and biodiversity loss in the Western Ghats, with a focus on developing integrative conservation strategies that are ecologically sound, socially inclusive, and contextually grounded. Emphasis is placed on landscape-level planning, ecological connectivity, and community-based stewardship, alongside the incorporation of indigenous ecological knowledge systems. Through a synthesis of case studies, policy analysis, and ecological data, the research aims to contribute to the development of adaptive, participatory, and regionally tailored conservation models that can safeguard the ecological integrity and cultural heritage of the Western Ghats in an era of accelerating environmental change.

Review of Literature -

Western Ghats have been extensively studied for their ecological richness and high levels of endemism. Myers et al. (2000) identified the region as one of the world's eight "hottest hotspots" of biodiversity, emphasizing its global conservation priority. The Ghats host over 7,400 species of flowering plants, many of which are endemic, along with diverse faunal groups including amphibians, reptiles, and mammals (Nair, 1991; Daniels, 1992). This biological wealth is intricately linked to the region's complex topography, varied microclimates, and long-standing human-nature interactions.

However, recent literature highlights the growing vulnerability of these ecosystems to anthropogenic pressures. Land-use change, driven by agriculture, urbanization, and infrastructure development, has led to habitat fragmentation and degradation (Kumar & Ramachandran, 2019). Studies by Jha et al. (2000) and Menon & Bawa (1997) show that forest cover loss in the Ghats is accelerating, particularly in low-elevation zones where human settlement density is highest.

The Western Ghats have long been recognized as a global biodiversity hotspot, with exceptional levels of endemism and ecological complexity. Recent research continues to underscore the region's ecological significance while highlighting the mounting pressures it faces from both anthropogenic and climatic stressors.

Bathija and Sylvander (2023) critically examine the socio-political dimensions of conservation in the Ghats, revealing how exclusionary models—particularly the displacement of Adivasi communities from protected areas like Nagarhole—have led to cultural erosion and ecological disconnect. Their findings echo broader critiques of fortress conservation and advocate for inclusive, rights-based approaches that integrate local stewardship.

Climate change remains a dominant threat. The IUCN SSC Western Ghats Plant Specialist Group (2023) emphasizes the urgency of population-level assessments for critically endangered flora, proposing extinction risk evaluations and species recovery programs using the Red List methodology. Krishna et al. (2023) further highlight the vulnerability of amphibian populations to shifting temperature and rainfall patterns, noting range contractions and population declines among endemic species.

Ex-situ conservation has emerged as a complementary strategy. Tripathi et al. (2024) document the adaptability of over 100 native and naturalized plant species conserved at the Indian Institute of Horticultural Research, with special attention to rare and threatened taxa. Their work is supported by ethno botanical surveys across Maharashtra, Karnataka, and Kerala, which reveal the nutritional and medicinal value of wild fruits used by tribal communities (Deshmukh & Waghmode, 2023; Karun et al., 2023; Narayanan et al., 2023; Valvi et al., 2023). These studies reinforce the importance of preserving traditional ecological knowledge as part of biodiversity conservation.

Land-use change continues to fragment habitats, particularly on lateritic plateaus. A 2023 study by the Nature Conservation Foundation, cited by Mongabay India, shows how agroforestry and paddy cultivation are altering herpetofaunal diversity in northern Ghats. Meanwhile, a 2025 Mongabay India report revisits the Gadgil Committee's recommendations, advocating for zoning the Ghats into Eco-Sensitive Zones (ESZs) and enforcing bans on destructive activities such as quarrying and deforestation. Madhav Gadgil warns of increasing flash floods and landslides due to ecosystem degradation, calling for participatory governance and stronger policy enforcement.

Collectively, these studies highlight the need for integrative conservation frameworks that combine scientific assessments, community engagement, and traditional knowledge systems. They advocate for adaptive, inclusive, and regionally contextualized models capable of preserving the ecological pulse of the Western Ghats in an era of accelerating environmental change.

Methodology -

This review paper employs a qualitative, thematic synthesis of recent literature, policy documents, and case studies to explore biodiversity conservation strategies in the Western Ghats under the influence of climate stress. The methodology is designed to capture ecological, socio-cultural, and governance dimensions of conservation, drawing from interdisciplinary sources published between 2023 and 2024.

1. **Literature Selection and Scope**

Relevant peer-reviewed articles, institutional reports, and ethno botanical surveys were identified using academic databases such as Research Gate, Google Scholar, and organizational repositories including IUCN, Mongabay India, and the Indian Institute of Horticultural Research. Keywords used included "Western Ghats biodiversity," "climate change impacts," "indigenous conservation," "ex-situ conservation," and "eco-sensitive zones." Studies were selected based on their geographic relevance to the Western Ghats, publication regency (2023–2024), and thematic alignment with climate stress and conservation frameworks.

2. **Policy and Governance Review**

Key policy documents were analysed to understand the evolution and effectiveness of conservation governance in the region. These included:

- The Gadgil Committee Report (2011) and Kasturirangan Committee Report (2013), revisited through recent critiques and updates.

- State Biodiversity Action Plans from Kerala, Karnataka, and Maharashtra.
- The IUCN SSC Western Ghats Plant Specialist Group Report (2023), which provided updated Red List assessments and species recovery frameworks.

The review focused on implementation gaps, community participation, and the integration of ecological science with policy instruments.

3. **Case Study Identification and Analysis**

Three case studies were selected to illustrate successful conservation interventions:

- **Sacred grove preservation in Kerala**: Highlighting community-led protection of microhabitats with high endemic species density.
- **Biodiversity blocks in Karnataka**: Documenting ex-situ conservation of native and threatened plant species.
- **Watershed restoration in Maharashtra**: Showcasing participatory approaches to land and water management with ecological co-benefits.

Each case was evaluated based on ecological outcomes, Replicability, and socio-cultural integration, using published field reports and ethnographic surveys.

4. **Thematic Categorization and Synthesis**

All findings were organized into four thematic domains:

- **Climate vulnerability and species sensitivity**
- **Habitat fragmentation and land-use change**
- **Indigenous knowledge and community stewardship**
- **Policy coherence and governance challenges**

This thematic structure enabled a holistic synthesis of ecological data, conservation models, and socio-political dynamics, allowing for the identification of gaps and opportunities in current strategies.

Results and Discussion -

The synthesis of recent literature, policy reviews, and case studies reveals a multifaceted landscape of biodiversity conservation in the Western Ghats, shaped by ecological vulnerability, climate stress, socio-political tensions, and evolving governance frameworks. The discussion is organized into four interrelated thematic domains that reflect the complexity and urgency of conservation efforts in this globally significant region.

1. Climate Vulnerability and Species Sensitivity

Recent ecological assessments underscore the heightened sensitivity of endemic species in the Western Ghats to climate variability. Amphibians, montane flora, and herpetofauna are particularly vulnerable due to their narrow ecological niches and limited dispersal capacity. Krishna et al. (2023) report significant range contractions among amphibian populations, correlating with rising temperatures and erratic rainfall patterns. These findings are consistent with broader climate models predicting increased frequency of extreme weather events and altered monsoonal dynamics across the region.

The IUCN SSC Western Ghats Plant Specialist Group (2023) emphasizes the need for population-level assessments of critically endangered flora, advocating for extinction risk evaluations and species recovery programs. Their Red List-based framework provides a scientific foundation for prioritizing conservation actions, yet implementation remains limited due to data gaps and resource constraints. These studies collectively highlight the need for climate-adaptive conservation strategies, including microhabitat restoration, assisted migration, and long-term ecological monitoring.

2. Habitat Fragmentation and Land-Use Change

Land-use transformation continues to be a dominant driver of biodiversity loss in the Western Ghats. Rapid urbanization, agricultural expansion, mining, and infrastructure development have fragmented habitats, disrupted ecological connectivity, and increased edge effects. Mongabay India (2025) documents the ecological consequences of quarrying and deforestation, particularly on lateritic plateaus and low-elevation zones. These activities not only degrade biodiversity but also exacerbate climate-induced risks such as landslides and flash floods.

The revisited Gadgil Committee recommendations advocate for zoning the Ghats into Eco-Sensitive Zones (ESZs), with graded restrictions on land-use activities. However, political resistance and lack of inter-state coordination have hindered effective implementation. The Kasturirangan Committee's diluted approach, which prioritized economic development over ecological integrity, has further complicated governance. These policy tensions underscore the need for a balanced framework that integrates ecological science with socio-economic realities.

3. Indigenous Knowledge and Community Stewardship

Ethno botanical studies reveal the deep ecological knowledge embedded within tribal communities across the Western Ghats. Tripathi et al. (2024) document the conservation of over 100 native and naturalized plant species in biodiversity blocks, many of which are used by local communities for food, medicine, and cultural practices. Surveys by Narayanan et al. (2023), Karun et al. (2023), and Valvi et al. (2023) highlight the nutritional and medicinal value of wild fruits consumed by tribal groups such as the Kattunaikka, Kuruma, and Paniya.

Sacred grove preservation in Kerala and community-led watershed restoration in Maharashtra exemplify successful participatory conservation models. These initiatives demonstrate how indigenous stewardship can enhance ecological resilience while preserving cultural heritage. However, Bathija and Sylvander (2023) caution against conservation frameworks that marginalize indigenous voices, citing cases of forced displacement and exclusion from decision-making. Their critique calls for a shift toward rights-based conservation that recognizes tribal communities as co-managers of biodiversity.

4. Policy Integration and Governance Challenges

Despite the existence of robust policy frameworks, governance challenges persist in biodiversity conservation across the Western Ghats. The Gadgil and Kasturirangan reports offer contrasting visions—one rooted in ecological zoning and participatory governance, the other favoring technocratic planning and economic growth. State Biodiversity Action Plans vary in scope and effectiveness, often lacking mechanisms for cross-sectoral coordination and community engagement.

The IUCN's call for species recovery programs and the emphasis on local governance in the Gadgil report remain underutilized. Institutional fragmentation, limited funding, and political inertia have impeded the translation of policy into practice. Moreover, conservation efforts are often siloed, with inadequate integration between forest departments, local panchayats, and civil society organizations.

To address these gaps, scholars and practitioners advocate for adaptive governance models that are flexible, inclusive, and responsive to ecological feedback. Such models must incorporate scientific assessments, traditional knowledge systems, and participatory mechanisms to ensure long-term sustainability.

Synthesis

The reviewed literature and case studies converge on a central insight: effective biodiversity conservation in the Western Ghats requires a paradigm shift from exclusionary, top-down approaches to integrative, community-cantered frameworks. Climate resilience, ecological connectivity, and cultural continuity must be treated as interdependent goals. The Western Ghats, as a living landscape, demand conservation strategies that are not only scientifically sound but also socially just and politically feasible.

Conclusion -

The Western Ghats, a globally recognized biodiversity hotspot, are facing unprecedented ecological stress due to the dual pressures of climate change and anthropogenic disturbance. This review has synthesized recent findings from ecological studies, policy analyses, and community-based conservation efforts to highlight the multifaceted nature of these challenges. Endemic species are increasingly vulnerable to shifting climatic conditions, while habitat fragmentation continues to erode ecological connectivity and resilience.

The analysis reveals that while policy frameworks such as the Gadgil and Kasturirangan reports offer valuable guidance, their implementation remains inconsistent and often disconnected from ground realities. Indigenous communities, despite possessing deep ecological knowledge and cultural ties to the land, are frequently marginalized in formal conservation efforts. Successful case studies—such as sacred grove preservation and biodiversity blocks—demonstrate that inclusive, locally rooted approaches can yield both ecological and social benefits.

Ultimately, the conservation of the Western Ghats requires a paradigm shift toward integrative, adaptive, and participatory models. These must bridge scientific insight with traditional knowledge, and policy ambition with grassroots action, to ensure that this ancient landscape continues to thrive in the face of accelerating environmental change.

Essential Recommendations -

1. **Implement Climate-Adaptive Conservation**
   - Prioritize species vulnerability assessments and microhabitat restoration.
   - Integrate climate modelling into biodiversity planning to anticipate ecological shifts.
2. **Empower Indigenous Communities**
   - Recognize tribal groups as co-managers of biodiversity.
   - Institutionalize traditional ecological knowledge in conservation policies and programs.

3. **Strengthen Eco-Sensitive Zoning**
    - Enforce land-use regulations in critical habitats.
    - Halt destructive activities like quarrying and deforestation in designated zones.
4. **Scale Up Community-Led Models**
    - Expand successful initiatives such as sacred grove protection and watershed restoration.
    - Provide financial and technical support to local conservation groups.
5. **Enhance Policy Coordination**
    - Improve collaboration between forest departments, biodiversity boards, and local governance.
    - Ensure transparency and accountability in conservation implementation.

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An Analytical Study on India Electric Mobility Index (IEMI) Developed By Niti Aayog

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Abstract

This review article discusses the current state of EV market around the globe with special focus on India, highlighting challenges and opportunities for EV in the Indian context. EV or electric mobility is a growing component in the transportation sector of India. It is expected to spearhead India's progress towards net-zero by 2070. Considering the huge transition required to adopt EV from current fossil fuel-based transportation system, it is important that India builds robust electric mobility infrastructure throughout the country. India Electric Mobility Index (IEMI) is a multi-faceted evaluation tool developed by NITI Aayog. It serves as the first step towards understanding, evaluating and improving the electric mobility infrastructure from technology, administration and human viewpoints on a national scale. This article analyses various components of IEMI including its parameters, data collection process, score calculation methodology and scoring techniques. It also provides a list of interventions helpful for the states and UTs of India to improve their IEMI performance.

Keywords - EV, Electric Mobility, India Electric Mobility Index

Introduction

The India Electric Mobility Index (IEMI) is a novel and innovative approach developed and championed by NITI Aayog, which is aimed at understanding the state of EV supportive infrastructure and EV research, and evaluating effectiveness thereof through 16 indicators that cover three key areas viz.—Transport Electrification Progress, Charging Infrastructure Readiness, and EV Research & Innovation Status. The index provides a complete snapshot of the electric mobility in a state or UT in the form of a composite score out of 100, known as IEMI score (Niti Aayog, 2025)[1].

In line with Article 1 of the Indian Constitution (Legislative Department, 2025)[2] and Competitive Federalism espoused by NITI Aayog (Niti Aayog, 2025)[3], the IEMI strives to promote healthy competition amongst states and union territories to drive the nation towards enhanced sustainability and electric powered transportation system. The IEMI score can be construed as a percentage of e-mobility objectives achieved by the respective state or UT.

According to an MDPI research paper published in May 2023 (Ferrer et al., 2023)[4], transportation sector is responsible for 15% of anthropogenic GHG, 23% of global energy-related, and 8.7 Gt CO_2-eq emissions. As a consequence of this, the same sector offers significant opportunities for the mitigation of anthropogenic carbon footprint. India, being the world's third largest CO_2 emitter wherein transportation constitutes the biggest piece of the pie (Jain et al., 2023)[5], it can set an example by mitigating transportation related GHG emissions through the development of a robust electric mobility infrastructure and EV market. From 2001 to 2020, CO_2 emissions from the Indian transportation sector increased from 155.9 Mt to 368.2 Mt. wherein road transport produced 88% of all CO_2 emissions (Jain et al., 2023)[5]. IEMI should serve as a milestone in the development and administration of electric mobility infrastructure in the country.

Objectives of the study

1. This paper aims to –
2. provide an overview of electric mobility across the globe with special focus on India
3. study IEMI by analysing its multi-parameter framework
4. suggest broad strategies to improve the performance of a state or UT on IEMI.

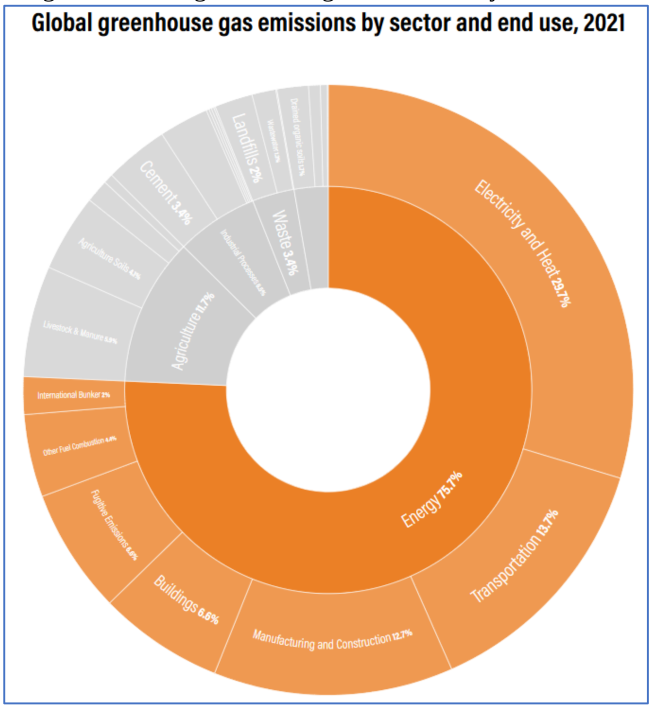
b) The structure of this paper is as follows:

The paper starts by giving an overview of sector-wise GHG emissions. Then it explores the EV as a strategy to mitigate GHG emissions with special focus on India. In the last part, it attempts to provide a comprehensive description of IEMI.

The sector-wise GHG emissions around the globe and in India

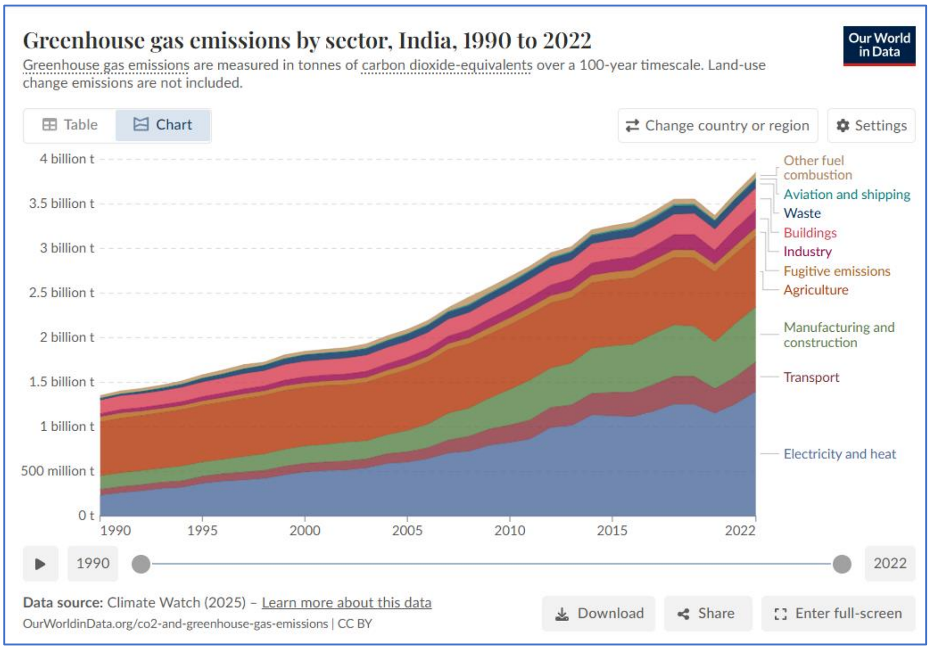
According to World Resources Institute 2021 report[6], transportation contributes to 13.7% of total GHG emissions. The contribution of the transportation sector is not same everywhere. In the US, for example transportation is a much larger contributor than the global average. According to a chart published by ourworldindata.org[7] based on the data provided by Climate Watch, the contribution of transportation sector in India grew from 4.88% in 1990 to 8.62% in 2022, reaching a whopping 332 million tonnes CO2 equivalent.

Image 1 – Global greenhouse gas emissions by sector and end use



Source – World Resources Institute (Data source - Climate Watch) [6]

Image 2 – Global greenhouse gas emissions by sector, India, 1990 to 2022



Source – Our World in Data (Data source - Climate Watch)[7]

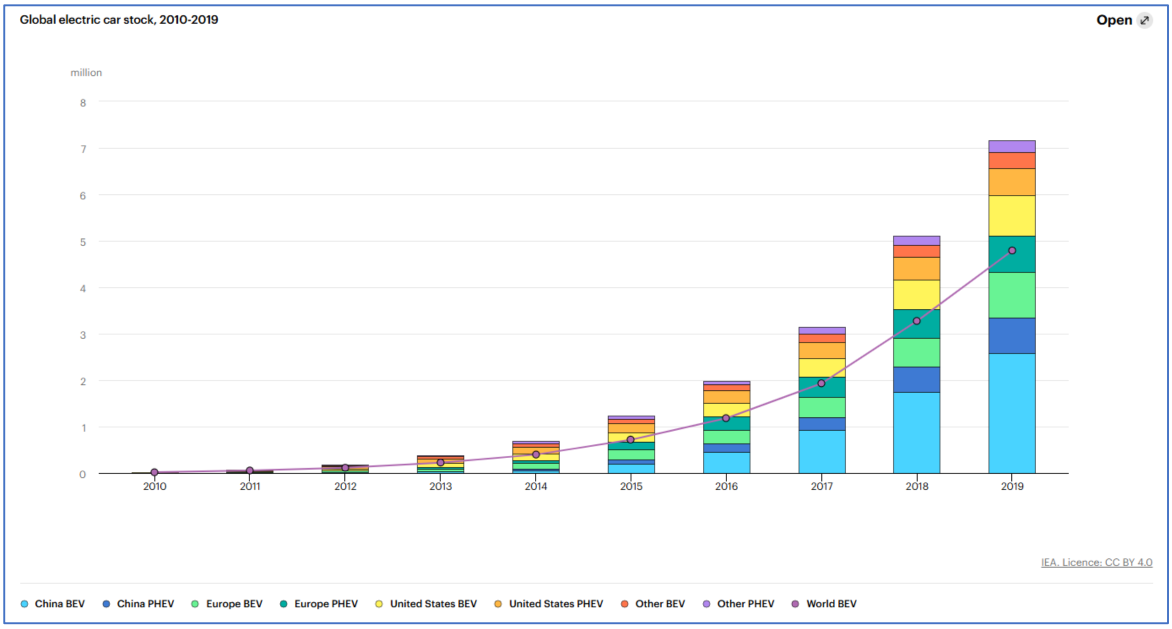
Growth of EV as a strategy for mitigating transportation specific GHG emissions

There are different views on life-cycle GHG emissions of electric vehicles, as one must consider the carbon footprint of electricity used for the production and subsequent regular charging of electric vehicles. However, as per Hirz et al.[8], when considering low-carbon electric power generation, the life cycle related greenhouse gas emission impact of electric cars is significantly lower than those of cars driven by combustion engines, even if their footprint of vehicle production might be higher than those of conventional cars. A significant advantage of EVs compared to conventional gasoline vehicles is their energy efficiency. EVs use approximately 87%–91% of the energy from the battery and regenerative braking to propel the vehicle. Gasoline vehicles only convert about 16–25% of the energy from gasoline into movement [averaging highway and city driving] (US EPA, 2025)[13]. In India, 41.6% of electricity generation is from non-fossil fuel sources (GOI, Ministry of Power)[9], and the same is expected to increase in upcoming decades due to government policies. Hence, a robust EV sector supported by low-carbon electric power generation will prove to be an effective strategy for India towards achieving net-zero by 2070.

State of electric vehicles around the globe and in India

Following a decade of tremendous expansion, by the end of 2020, the global EV stock (cars, vans, trucks, buses and 2 and 3 wheelers) was around 50 million (IEA, 2025)[15]. Sales of electric cars topped 2.1 million globally in 2019, taking the global stock to 7.2 million. Electric cars registered a 40% year-on-year increase. Indications of a continuing shift from direct subsidies to policy approaches that rely more on regulatory and other structural measures – including zero-emission vehicles mandates and fuel economy standards – have set clear, long-term signals to the auto industry and consumers that support the transition in an economically sustainable manner for governments (Global EV Outlook, 2020)[10]. Owing to these favourable factors, the global EV stock reached around 140 million in 2024 (IEA, 2025)[15].

Image 3 – Global electric car stock, 2010-2019



Source – Global EV Outlook, 2020[10]

In India, currently the EV market is small. But India aims for 100% electric vehicle sale by 2030. The CAGR of electric vehicles since 2020 is 28.12%. Once accounting for just 0.5% of total vehicle sales in 2018, EVs rose to 7.7% of new vehicle sales in 2024, with over 6.5 million EVs operating on Indian roads as on June 2025 (IEMI Report 2024)[18]. According to a survey in Ludhiana, 36% of the existing car and two-wheeler owners were enthusiastic about shifting to electric vehicle. Telangana state Government is also encouraging the use of EVs by eliminating road tax for EV owners, planning to build charging facilities at metro stations in Hyderabad and proposing to replace diesel-run public transport vehicles with electric vehicles in Hyderabad. In November 2018, the Delhi Govt. released a draft policy that is aiming to convert 25% of their vehicles to EVs by offering various incentives and by setting up charging infrastructures in both residential and non-residential areas. This policy aimed to develop a charging point at every 3 km by offering a subsidy of 100% (up to INR 30,000) and waive off the road tax, parking charges, and registration fee for EV by 2023. In Mumbai-Pune highway, a private firm named Magenta Power is also working for setting up EV charging infrastructure (Goel et al.)[11].

Below is a list of the major nation-wide initiatives by GoI to promote EV market (Business Outreach, Sep, 2025)[14]:

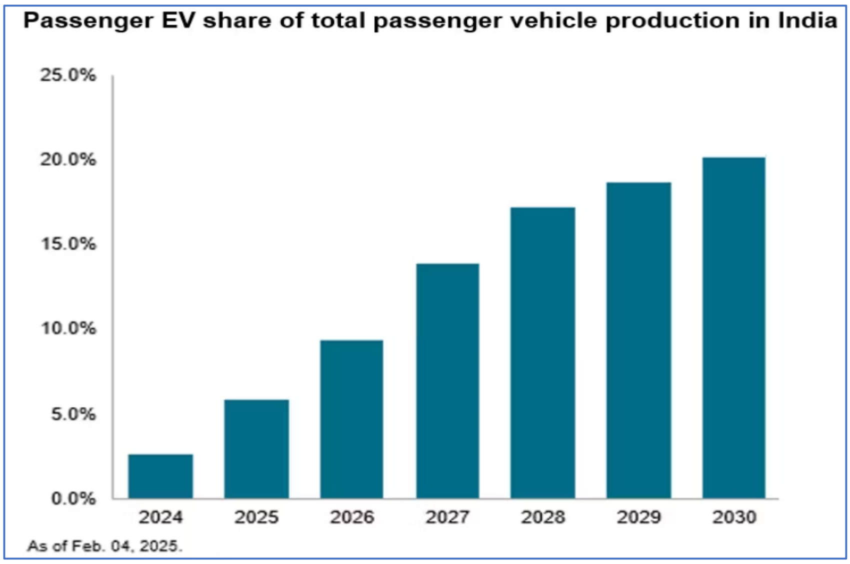
1) FAME [Faster Adoption and Manufacturing of Hybrid and Electric Vehicles] Scheme – a multi-phased subsidy scheme focusing on EVs, battery capacity, charging infrastructure, domestic manufacturing and integration with renewable energy.

2) GST Reduction, Tax Incentives, and Regulatory Support - GST on EVs has been reduced to 5%, buyers are eligible for a claim on an income tax deduction, EVs are exempt from permit requirements [for commercial use] and the government has issued green license plates for EVs.

3) Production-linked Incentive [PLI] Scheme - The government has introduced PLI for the Advanced Chemistry Cell Batteries with an outlay of ₹18,100 crore.

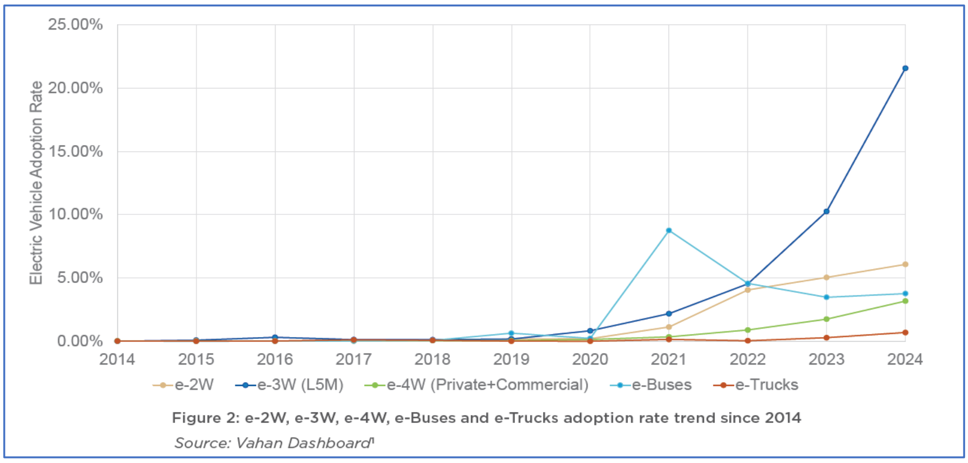
4) Charging Infrastructure Push - The Indian government has set a target of installing over 22,000 public charging stations by 2026.

Image 4 – Passenger EV share of total passenger vehicle production in India



Source – S&P Global Mobility[12]

Image 5 – Electric vehicle adoption rate in India



Source – India Electric Mobility Index 2024[18]

India Electric Mobility Index (IEMI) – an evaluation tool for electric mobility infrastructure in India
India's EV sector suffers from various obstacles viz. unavailability of skilled repair and maintenance personnel, high capital cost, lack of consumer awareness about government initiatives for EVs, import dependence for raw materials of batteries, limited driving range of most EVs, environmental impact of battery production and disposal and lack of robust charging infrastructure (Goel et al.)[16]. Many of these factors can be mitigated only through support from the government and various public institutions. IEMI has been designed to critically evaluate and analyse the state of electric mobility infrastructure in a state or UT.

Objectives of IEMI (India Electric Mobility Index 2024)[18]

1) To recognise states that are performing well in this sector
2) To identify key success factors that have an outsized impact on e-mobility development
3) To encourage states to take a more proactive approach to e-mobility
4) To support evidence-based policymaking for sustainable EV growth

Parameters of IEMI (India Electric Mobility Index 2024)[18]

Weight	Key Area	Parameter	Type	Description
50%	Transport Electrification Progress	EV Registration and Adoption rate (25%) *Of private and commercial vehicles*	Outcome	Share of electric vehicles registered in the state as per Vahan data
		Transport Electrification Initiatives (11.5%) *For governance, transition, operational support and fuel price parity*	Enabler	State-led efforts to plan, regulate and accelerate EV adoption
		Purchase Incentives (13.5%)	Enabler	State subsidies, tax exemptions and fee exemptions offered by state
30%	Charging Infrastructure Readiness	EV to EV charger ratio (15%)	Outcome	Total no. of public chargers and charging stations in the state
		Charging Infrastructure Initiatives (10.5%) *Including capital subsidies for charger infrastructure, and formulation of bylaws for charging*	Enabler	Government fiscal and non-fiscal incentives to promote charging infrastructure
		Total renewable energy capacity and its share (3%)	Enabler	Share of renewables in the total installed electricity generation capacity
		Power availability (1.5%)	Enabler	Gap between power demand and supply
20%	EV Research and Innovation Status	Startups (10%)	Outcome	No. of e-mobility startups in a state
		EV Research and Innovation (6%) Initiatives	Enabler	State efforts to promote electric mobility research
		EV Patents (4%)	Enabler	Total no. of active patents related to e-mobility in a state

Break-up of parameters and their weights (India Electric Mobility Index 2024)[18]

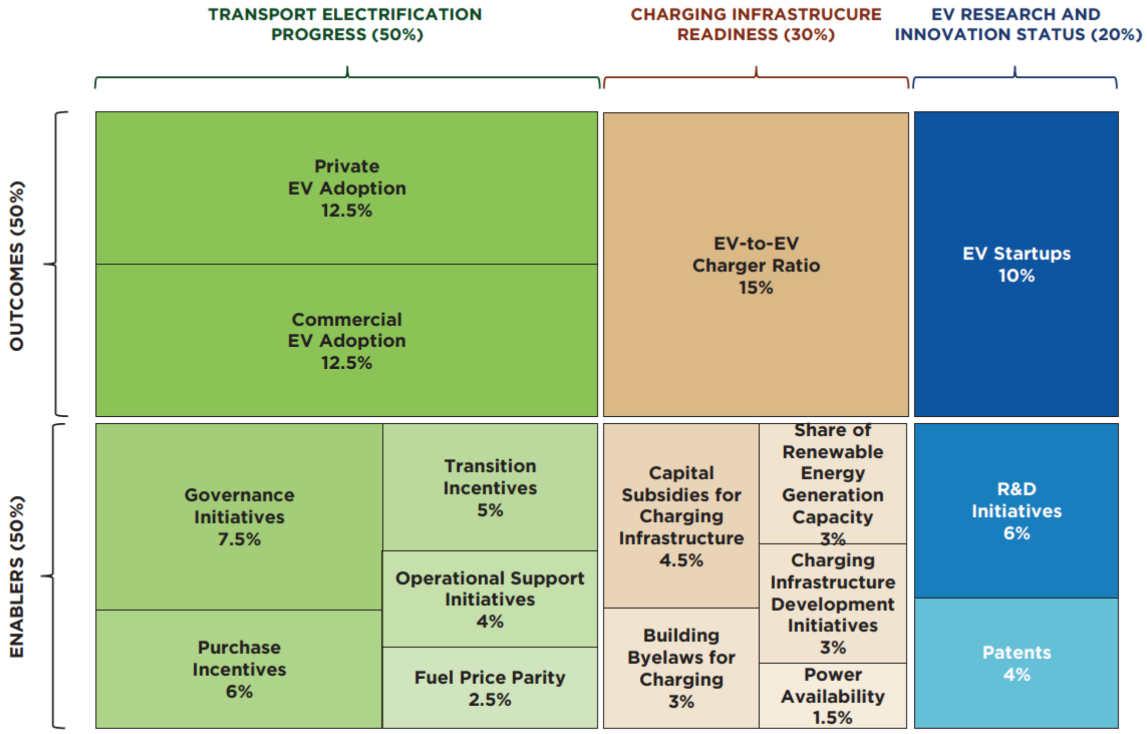
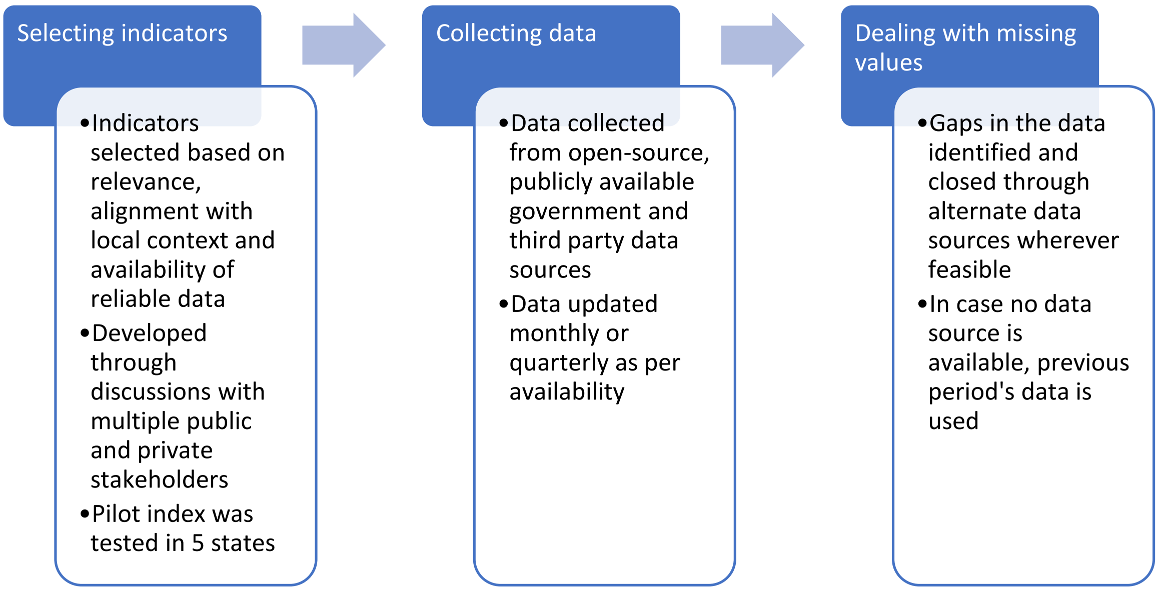


Figure 8: IEMI Theme and Indicator Weightages

Source – Niti Aayog[18]

a) Data collection process of IEMI (India Electric Mobility Index 2024)[18]



b) Calculation of score (India Electric Mobility Index 2024)[18]

Table 1: Theme Weightages and Theme Score Notations

Theme	Theme Weightage	Theme Score
Transport Electrification Progress	50% (T_1)	S_1
Charging Infrastructure Readiness	30% (T_2)	S_2
EV Research and Innovation Status	20% (T_3)	S^3

For any state or UT,

$$IEMI\ score = T_1S_1 + T_2S_2 + T_3S_3.$$

Table 2: Indicator Weightage Notations

Indicator	Indicator Weightage	Indicator score
Indicator 1	(I_1)	K_1
Indicator 2	(I_2)	K_2
Indicator n	(I_n)	K_n

For any state or UT,

$$Theme\ Score = \frac{\sum_{i=1}^{n} I_i K_i}{W_T}, I_i \in T,$$

where

W_T is the theme weightage of theme T and

$I_i \epsilon T$ epresents indicator i belonging to theme T.

c) Scoring methods (India Electric Mobility Index 2024)[18]

The indicators are evaluated based on two scoring methods: absolute and relative scoring. In the absolute scoring method, a state is scored based on the number of given initiatives it is implementing. In the relative scoring method, a state is scored in comparison with the performance of other states and UTs. Relative Scoring Indicators are:

1) private EV adoption
2) commercial EV adoption
3) purchase incentives
4) fuel price parity
5) EV-to-EV charger ratio
6) share of renewable energy generation capacity
7) power availability
8) EV Startups and EV Patents.

Absolute or Binary scoring Indicators are:

1) governance initiatives
2) transition initiatives
3) operational support initiatives
4) charging infrastructure development initiatives
5) building bylaws and mandates and R&D initiatives. Each indicator's scoring method is tailored to rationalise the evaluation process.

d) IEMI scores 2024 (India Electric Mobility Index 2024)[18]

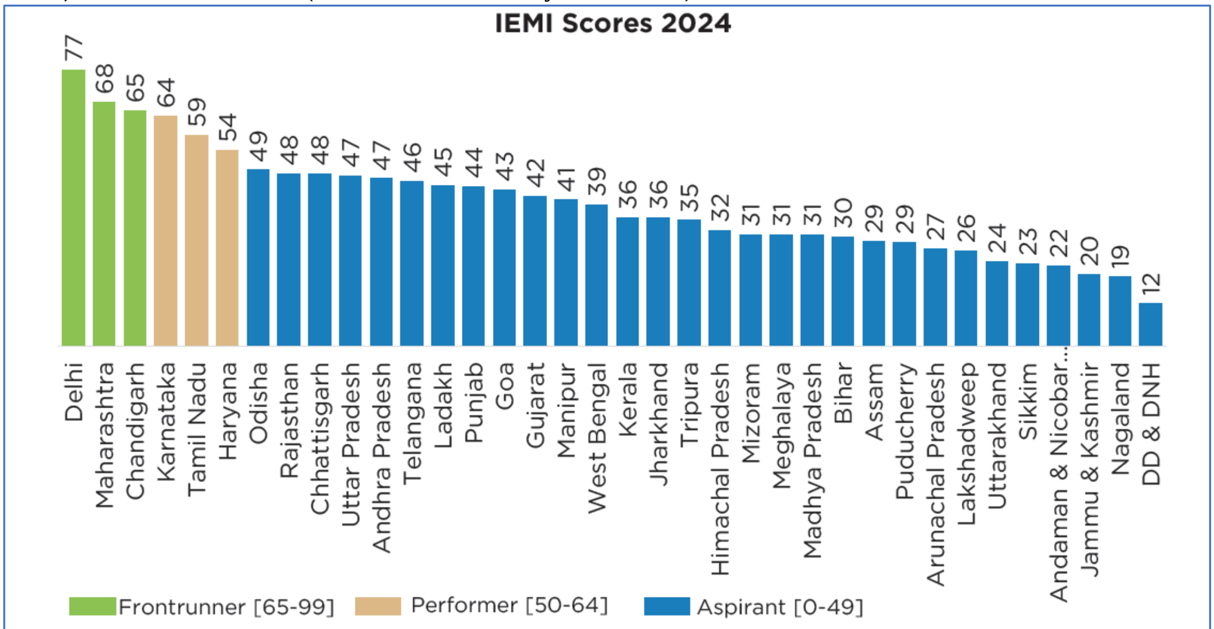


Figure 9: IEMI Score for 2024

e) Recommendations to improve the score

Following are the recommendations applicable to all the states and UTs in general that will help them improve their IEMI scores:

1) The states lacking an EV policy should frame and notify a detailed policy in this direction to develop a comprehensive approach to the EV.
2) The states struggling to grow their EV sector despite robust policy framework should consider developing fiscal and non-fiscal measures to promote EV, in the form of concessions, exemptions and incentives.
3) Some states need to consider setting up a high-level interdepartmental committee to steer the development of electric mobility in the planned direction.
4) To address the scarcity of skilled manpower in this sector, the states and UTs can set up EV skill development centres and offer e-mobility courses.
5) Every state and UT should have a dedicated website or app for EV awareness and support.
6) The states lying in remote areas with sufficient land availability can offer concessional land rates for charging infrastructure setup.
7) Providing single window system for approvals to setup charging infrastructure is a prerequisite to develop EV in India.
8) Collaboration between government agencies and top universities to promote EV oriented R&D is the need of the hour to develop state of the art EV.
9) Regions such as Delhi can consider setting up low emission zones in designated areas.
10) To facilitate transition from old vehicles to EVs, some states need to design attractive scrapping policies and incentives.

Conclusion

It is clear from this study that EV is a high-potential "green" sector that will drive India's progress towards becoming net-zero by 2070. Given that EV embodies a huge transition from decades old fossil fuel-based transportation system, it requires significant investment in electric mobility infrastructure. The India Electric Mobility Index (IEMI) is a well-articulated tool developed by NITI Aayog to evaluate the state of electric mobility infrastructure in each state and UT. This tool not only highlights weak areas for a state/UT but also provides a direction to its efforts towards promoting electric mobility. The concerned state/UT can aspire to stand out as a leader in the EV revolution of India, and set an example for other states/UTs in a friendly competitive federalism spirit.

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Sustainable Development through Green Finance

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Abstract

The growing urgency of climate change, natural resource depletion, and environmental degradation has positioned environmental sustainability at the forefront of international economic and policy debates. Green finance is seen as a revolutionary instrument that captures environmental factors within financial institutions, channelling flows of capital into environmentally friendly activities like renewable power, clean technologies, sustainable agriculture, and low-carbon infrastructure. This article explores the development, tools, and policy frameworks of green finance and emphasizes its contribution towards sustainable development. Based on qualitative research utilizing secondary data from academic papers, international reports, and market data, the research reviews the world and regional trends with particular emphasis on India.

The findings support a green financial instruments' growth that has been quick and expansive, especially in the rise of green bonds and ESG-linked funds that have become crucial in engaging resources for climate adaptation and mitigation. The growth, though, is hindered by issues of greenwashing, incomparable taxono- mies, and impaired accessibility within developing economies. The discussion reiterates that while green fi- nance holds potential for creating innovations, reducing climate risks, and generating employment, it needs more robust regulatory bases, transparency, and global cooperation to achieve its full impacts.

This paper argues that green finance is not just a substitute investment strategy but a required route toward environmental sustainability and fulfilling international commitments like the Paris Agreement and the United Nations Sustainable Development Goals (SDGs). This research adds to increasing literature as it connects theory views with real-world expertise, providing guidance for policymakers, financial institutions, and stake- holders to enhance the embedding of sustainability within the financial landscape.

Keywords: Green finance, ESG investments, Green bonds, Sustainable development, Climate finance, Re- newable energy, SDGs.

Introduction

The 21st century is marked by rapid industrialization, urbanization, and economic growth, but these advances have also led to environmental challenges such as air pollution, global warming, and biodiversity loss. The **Paris Agreement (2015)** and **UN Sustainable Development Goals (SDGs)** have reinforced the global con- sensus that economic growth must align with ecological sustainability.

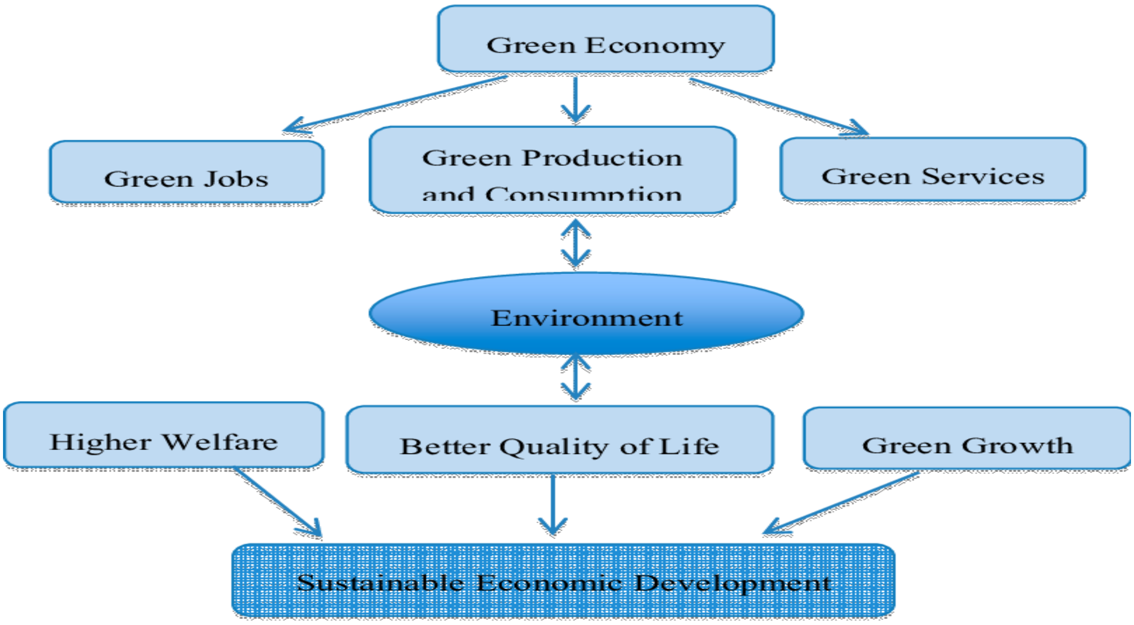
Green finance refers to financial investments and instruments that support projects with positive environ- mental impacts, including renewable energy, energy efficiency, waste management, and biodiversity conser- vation. It represents the fusion of economic development and environmental preservation.

Green finance refers to the allocation of capital and financial resources toward projects, businesses, and pol- icies that deliver environmental benefits while also ensuring economic returns. It includes instruments such as **green bonds, sustainable loans, carbon credits, environmental impact funds, and ESG (Environmen- tal, Social, and Governance) investments**. These instruments aim to finance renewable energy, sustainable agriculture, waste management, energy-efficient infrastructure, and climate adaptation strategies.

By aligning finance with sustainability goals, green finance acts as a **bridge between economic development and environmental protection**, ensuring that growth does not compromise the ecological balance.

Growing global recognition of climate change, environmental deterioration, and scarcity of resources has brought green finance to the centre stage of economic, scholarly, and policy debates. Conventional financial systems have tended to focus on maximization of short-term profits without much consideration for environ- mental impact. Increasingly, though, the intensifying effects of global warming, loss of biodiversity, and un- sustainable consumption have underscored the importance of ensuring financial flows in line with environ- mental sustainability objectives.

Green finance is a new turn, combining environmental factors in financial decisions to enhance long-term sustainability. Through the channelling of capital to renewable energy, clean technologies, sustainable agri- culture, and green infrastructure, green finance seeks to reduce climate risks while building economic resili- ence. Organizations like the United Nations, World Bank, and governments of countries alike increasingly see green finance not just as a choice but also as a need to pursue sustainable development and fulfil global obligations like the Paris Agreement and the UN Sustainable Development Goals (SDGs).



Literature Review

IFC (2019) *Green Finance: A Bottom-up Approach to Track Existing Flows*: This publication from the International Finance Corporation highlights efforts to track and measure green finance flows, particularly within private financial institutions. It suggests the feasibility of estimating these flows through a "bottom-up" approach, providing practical methods to assess how financial institutions contribute to sustainable initiatives.

OECD (2020) *Developing Sustainable Finance Markets*: This work from the Organisation for Economic Co-operation and Development focuses on the broader development of sustainable finance markets, offering insights into how environmental considerations can be systematically integrated into financial systems. It provides context for policymakers and market participants aiming to foster sustainable investment environments.

Fu, Xu, and Zhang (2023) 'Green Finance and Sustainable Development: Evidence from Global Financial Markets': This study examines the relationship between green finance and sustainable development, drawing evidence from global financial markets. The research highlights the measurable impact of green finance initiatives on economic and environmental outcomes, supporting the effectiveness of such practices in promoting sustainability.

Chen et al. (2022) 'Digital Innovation and Sustainable Finance: The Role of Green Fintech': This paper explores the intersection of digital innovation and sustainable finance, specifically highlighting the role of green fintech in pro- moting environmental objectives within the financial sector. It shows how technology-driven solutions can accelerate the adoption of sustainable financial practices.

Ozili (2022) *Green Finance Research Around the World: A Review of Literature*: This review examines global trends, themes, and gaps in green finance research. It emphasizes challenges, opportunities, and emerging patterns in the field, providing a comprehensive overview for researchers and practitioners interested in sustainable finance development.

Research Gap

Existing studies discuss how green finance works, its benefits, and new technologies, but there is little research on how small and medium enterprises (SMEs) in developing countries use green finance. In particular, it is not well understood how government policies, access to finance, and digital tools together help SMEs adopt sustainable finance. This shows a need for more research on practical ways to implement green finance in different economic settings.

Objectives of the Study

1. To analyse the concept and evolution of green finance in the global and Indian context.
2. To examine the role of green financial instruments in advancing environmental sustainability.
3. To identify challenges and barriers in implementing green finance in developing economies.

Research Methodology

1. Research Design

A. Qualitative Research Design

Purpose: To interpret and understand concepts, policies, frameworks, and practices related to green finance.

Application:

- Analysing sustainability reports of banks and institutions.
- Understanding regulatory frameworks like SEBI's BRSR, EU Taxonomy, and TCFD recom- mendations.

Justification: Green finance is conceptually complex, involving environmental, financial, and social dimensions, which are better captured through qualitative analysis rather than pure numerical data.

B. Descriptive Research Design

Purpose: To systematically describe the current state of green finance instruments, policy frame- works, and institutional roles.

Application:

- Presenting trends in green bond issuance globally and in India.
- Describing the role of banks, DFIs, and asset managers in promoting sustainable finance.

Justification: Descriptive research enables the study to **present factual information** and compare practices across regions.

C. Exploratory Research Design

Purpose: To explore emerging phenomena and trends in green finance that are not yet widely estab- lished.

Application:

- Examining green fintech innovations and block chain-based carbon trading.
- Investigating integration of sustainable finance with SDGs.

Justification: Since green finance is evolving rapidly, exploratory research helps **identify patterns, opportunities, and challenges** that may not yet be fully documented.

Research Approaches

1. **Mixed- Method Research Approach:** That involves both quantitative and qualitative method to gather and analyse data.

   a) **Quantitative Research Approach:** This involves measuring numerical data related to market growth and performance. The study planned to measure the following specific quantitative data:

      i) **Growth of Green Bonds in India:** To measure in **INR billions.** Compound Annual Growth Rate (CAGR): To show the exponential growth of green bond issuance over a specific period. Formula: CAGR = (Beginning Value/ Ending Value)1/n−1
      ii) **ESG Fund Inflows:** Calculating the net flow rate or percentage change: To track investor inter- est and capital movement into sustainable funds over quarters or years. Formula like Flow = Purchase- Sales
      iii) **Carbon Credit Trading Volumes:** Volume Weighted Average Price (VWAP): To calculate the average price of credits traded over a day, weighted by volume. Formula, VWAP= $\sum$(Price×Volume) /$\sum$Volume
      iv) **Thematic Correlation:** Regression Analysis: To explore the relationship between green fi- nance (as a variable) and environmental performance (e.g.CO_2 emissions reduction). Formula, $Y=\beta 0+\beta 1X+\epsilon$ (Simple Linear Regression)

B) Qualitative Research Approach: This focuses on analysing non-numerical data to gain deeper insights:

Document Analysis: Analysing policy reports, sustainability reports, and guidelines (e.g., SEBI BRSR and EU Taxonomy).

Content Analysis: Extracting thematic patterns from research articles, institutional practices, and case studies.

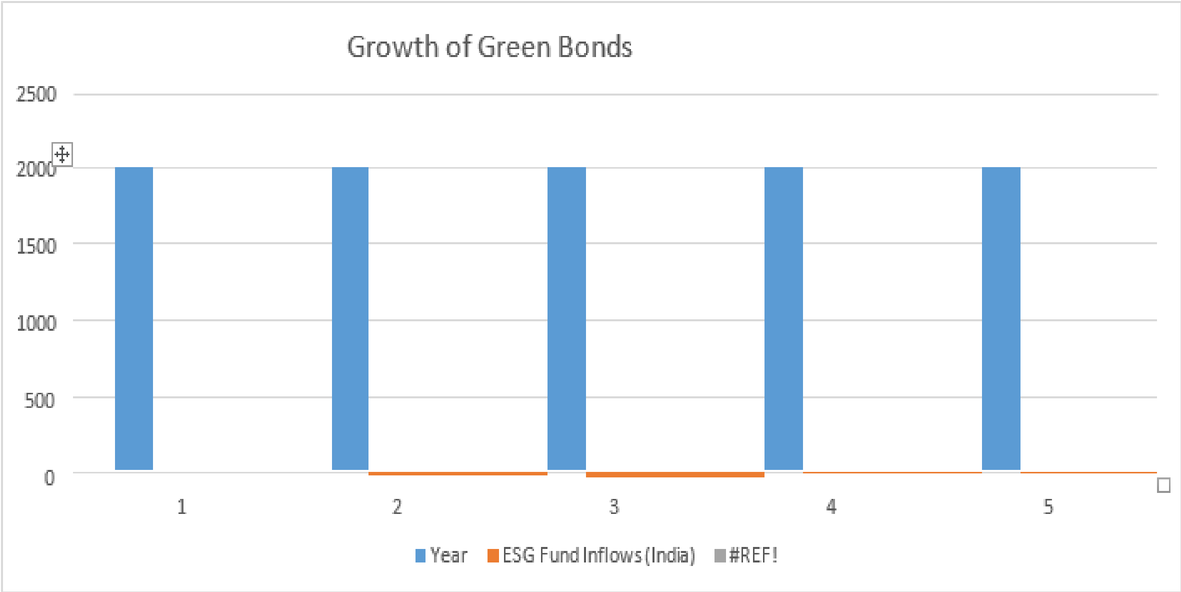
Case Study Analysis: Examining specific high-profile initiatives, such as India's sovereign green bond (2023) or the EU Green Deal implementation.

Data Analysis & Interpretation

Growth of Green Bonds Globally and in India:

Sample Data (USD Billion):

Year	Global Green Bond Issuance	India Green Bond Issuance
2018	167	2
2019	257	5
2020	270	7
2021	500	12
2022	520	15



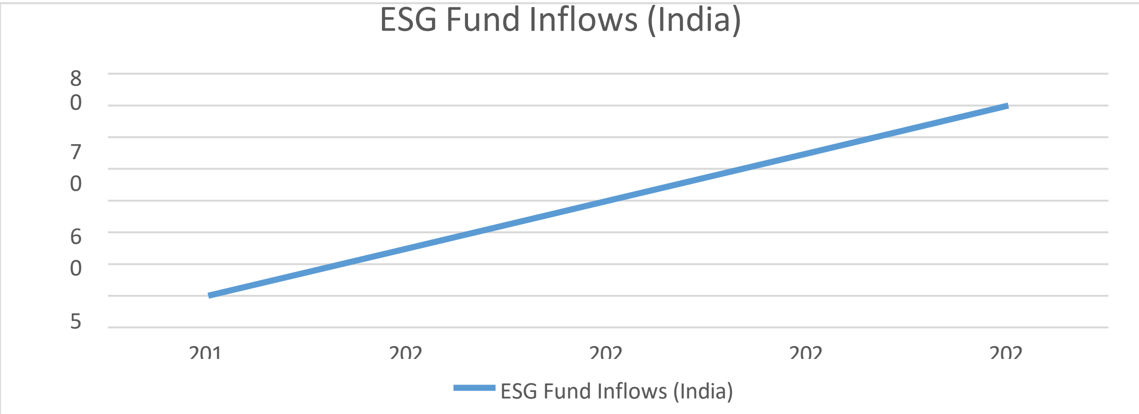
Interpretation:

- The global green bond market has shown exponential growth, more than tripling from 2018 to 2021.
- India’s green bond issuance is smaller in volume but shows a steady upward trend, reflecting increasing domestic interest in sustainable financing.

ESG Fund Inflows

- **Sample Data (INR Billion):**

Year	ESG Fund Inflows (India)
2019	10
2020	25
2021	40
2022	55
2023	70



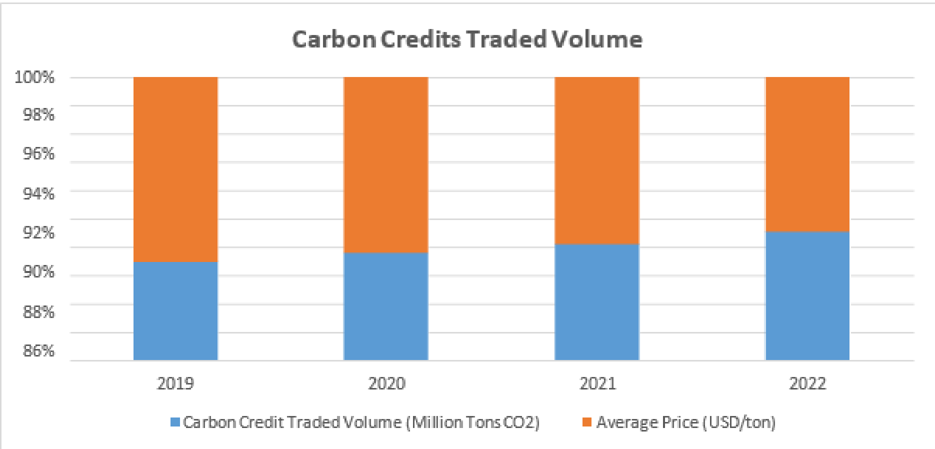
Interpretation:

- ESG fund inflows in India are increasing year-on-year, indicating growing investor confidence in sustainable investment strategies.
- This demonstrates a positive correlation between sustainability performance and financial attractiveness

Carbon Credit Trading Volumes

Sample Data

Year	Carbon Credit Traded Volume (Million Tons CO2)	Average Price (USD/ton)
2019	100	15
2020	120	17
2021	150	20
2022	180	22



Interpretation:

- Both trading volume and average price of carbon credits are increasing, showing a strengthening carbon market.
- This reflects heightened regulatory and market emphasis on carbon reduction and sustainability.

Results

Green finance is a powerful and necessary mechanism for advancing environmental sustainability and meeting international obligations like the Paris Agreement and the UN SDGs. The research supports the notion that the global green finance market is experiencing quick and expansive growth, with instruments like green bonds and ESG-linked funds proving crucial for channelling capital towards climate adaptation and mitigation efforts. This growth is evident in the exponential rise of international green bond issuance, which exceeded USD 500 billion in 2021, and the massive

AUM committed to responsible investment principles. Key results synthesized from the literature highlight several factors:

- Positive Correlation: ESG integration is found to have a positive correlation with long-term financial performance.
- Technological Innovations: Emerging trends like green fintech and block chain-based carbon trading promise to increase transparency and efficiency, democratizing sustainable investing and improving accountability in carbon markets.
- Policy Drivers: Mandatory reporting frameworks, such as the EU's SFDR and India's BRSR, are successfully pushing companies toward greater transparency in sustainability disclosures.
- Challenges Identified: Despite these successes, the full impact of green finance is hindered by significant barriers, including the risks of greenwashing, the problem of incomparable taxonomies for classifying 'green' activities, and impaired accessibility for developing economies.

Discussion

The discussion in the paper reiterates the profound potential and emerging necessity of **green finance** while confronting the systemic barriers that challenge its full implementation, particularly in developing economies.

Potential and Necessity:

- Creating Value: Green finance is shown to hold immense potential for creating innovations, reducing climate risks, and generating employment.
- Mitigating Risks: By channelling capital towards low-carbon infrastructure and clean technologies, it seeks to reduce climate risks while simultaneously building economic resilience.
- Beyond a Choice: Organizations worldwide, including the UN and World Bank, increasingly view green finance not just as a choice but as a necessity to pursue sustainable development and fulfil global obligations.

Challenges and Impediments: Despite the rapid growth of instruments like green bonds, the full impact is constrained by significant hurdles. The discussion highlights the critical need to address:

- Greenwashing: This issue undermines trust and challenges the integrity of the market.

- Incomparable Taxonomies: The lack of standardized definitions and reporting frameworks makes it difficult to compare and verify 'green' investments globally.
- Impaired Accessibility: This issue is particularly acute in developing economies, restricting their ability to fully capitalize on green financial flows.

Conclusion

Green finance has emerged as a vital pathway for achieving environmental sustainability. It is no longer seen as a minor or optional investment strategy but as a necessary approach to combine economic growth with ecological preservation. In today’s world, where climate change, resource depletion, and environmental degradation are becoming critical concerns, green finance provides solutions by directing capital towards sustainable projects and industries. Investments in renewable energy, energy efficiency, waste management, green bonds, and ESG-based (Environmental, Social, and Governance) practices show that finance can be a strong driver of positive change.

The importance of green finance is also reflected in its global recognition. International frameworks such as the Paris Agreement and the United Nations Sustainable Development Goals (SDGs) emphasize the role of finance in achieving climate action and sustainable development. By mobilizing funds for clean technologies and environmentally responsible businesses, green finance ensures that growth does not come at the cost of the planet. Moreover, it has the ability to generate new employment opportunities, promote innovation, and build resilience against climate risks.

However, despite its fast growth, the full potential of green finance has not yet been realized. The sector still faces many challenges. Weak or inconsistent regulations, lack of standardized reporting, and limited transparency create difficulties in ensuring accountability. The risk of greenwashing**—**where companies or institutions falsely claim to be environmentally friendly—undermines trust in green financial products. In addition, international cooperation is still fragmented, which slows down the overall effectiveness of green finance on a global scale.

In conclusion, green finance is not just about shifting money into different investments—it is about reshaping the financial system to serve both economic and environmental needs. It provides a bridge between growth and sustainability, proving that the two can go hand in hand if supported with the right policies and practices. With stronger rules, honest practices, and international collaboration, it can become a powerful force to combat cli- mate change and build a sustainable world for future generations.

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Imperial Study of Causes for Deterioration of Air Quality Level of Kolhapur in the Past Five years

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Abstract
The city of Kolhapur has been witnessing a steady decline in its air quality, raising serious concerns for the health of its residents and the environment. This imperial study investigates underlying causes responsible for deterioration of air quality between 2021 and 2025 by analyzing data collected from government air quality monitoring stations, published reports and scientific research studies. The study identifies rising vehicular emissions construction dust, industrial activities and biomass burning as dominant contributors of particulate pollution. Further, seasonal variations and meteorological factors exacerbate pollution wherein lower wind speeds and temperature inversions during winter and post-monsoon months trap pollutants close to ground level, thereby worsening air quality. Despite sustained efforts including implementation of the National Clean Air Programme (NCAP) and localized initiatives focusing on vehicle emission controls and dust suppression, air pollutant concentrations regularly surpass the National Ambient Air Quality Standards (NAAQS), reflecting gaps in enforcement and infrastructure. This study provides a comprehensive empirical narrative with data interpretation, discussions on policy effectiveness and recommendations for sustainable urban air management in Kolhapur.

Keywords: Kolhapur, air quality, NCAP. NAAQS, pollution causes, particulate matter, vehicles, construction dust, industrial emissions

Introduction

Urban air quality has become a significant issue in the recent years, and many Indian cities have been repeatedly placed in the list of the most polluted cities in the world. Even the city of Kolhapur located in the state of Maharashtra, once known for its lush green cover and rich cultural heritage has been struggling to maintain good air quality. Over the past few years, the city has been facing a silent but serious challenge in the form of steady decline in its ambient air quality. The worsening of air quality not only affects the environment, but also poses a serious threat to the health and daily lives of Kolhapur's residents. The residents of city are witnessing increased health issues such as respiratory problems, cardiovascular diseases, and other pollution-related illnesses.

Several interconnected factors such as rapid growth in population, increased vehicular traffic, building construction works, and on -going industrial projects around the city have contributed to the decline in air quality. As a result of which the city of Kolhapur has joined the list of non - attainment cities in India, that are habitually violating national pollution limits. In spite of implementing National and State Policy initiatives such as the National Clean Air Programme (NCAP) by the local administration, the city still struggles in handling the situation. The local authorities are facing pressure from the raising concern from the public to take corrective and preventive measures. This study attempts to empirically investigate the causes responsible for deterioration of air quality in Kolhapur from 2021 to 2025.

Air Quality Index (AQI)

An air quality index (AQI) is an approximation of how polluted the air currently is or how polluted it is forecast to become. As air pollution levels rise, so does the AQI, along with the associated public health risk (Wikipedia). Computation of the AQI requires an air pollutant concentration over a specified averaging period, obtained from an air monitor or model.

AQI or Air Quality Index is one of the most popular systems of communicating the level of air pollution to the public. It takes the complicated data on air pollution and transforms it into a single value, which reflects the cleanliness or pollution of the air and the associated health consequences that may be of concern. The AIQ is given on a scale of 0 and 500, wherein higher number indicates poorer air quality and higher health hazard. The AQI is determined using the level of major air pollutants, such as particulate matter (PM 2.5 and PM 10), ground-level ozone (O_3), carbon monoxide (CO), sulphur dioxide (SO_2) and nitrogen dioxide (NO_2). Each of these pollutants have certain breakpoints, which convert the concentration of the pollutant to AQI values that are assigned to one of the six AQI categories ranging between 'Good' and 'Hazardous'. Each of these category is identified by a particular color and health warning. Different countries have their own air quality indices, associated to different national air quality standards. The Ministry for Environment, Forest and Climate change launched the National Air Quality Index (AQI) with 'One Number – One Color – One Description' to help the Common Indian Man judge the Air Quality

AQI Category, Pollutants and Health Breakpoints

AQI Category (Range)	PM_{10} 24-hr	$PM_{2.5}$ 24-hr	NO_2 24-hr	O_3 8-hr	CO 8-hr (mg/m^3)	SO_2 24-hr	NH_3 24-hr	Pb 24-hr
Good (0-50)	0-50	0-30	0-40	0-50	0-1.0	0-40	0-200	0-0.5
Satisfactory (51-100)	51-100	31-60	41-80	51-100	1.1-2.0	41-80	201-400	0.5 – 1.0
Moderately polluted (101-200)	101-250	61-90	81-180	101-168	2.1- 10	81-380	401-800	1.1-2.0
Poor (201-300)	251-350	91-120	181-280	169-208	10-17	381-800	801-1200	2.1-3.0
Very poor (301-400)	351-430	121-250	281-400	209-748*	17-34	801-1600	1200-1800	3.1-3.5
Severe (401-500)	430 +	250+	400+	748+*	34+	1600+	1800+	3.5+

**One hourly monitoring (for mathematical calculations only)*

(Source: Ministry of Environment, Forest and Climate Change)

AQI and Associated Health Impacts

AQI	Associated Health Impacts
Good (0-50)	Minimal Impact
Satisfactory (51-100)	May cause minor breathing discomfort to sensitive people
Moderately polluted (101-200)	May cause breathing discomfort to people with lung disease such as Asthma and discomfort to people with heart disease, children and older adults
Poor (201-300)	May cause breathing discomfort to people on prolonged exposure and discomfort to people with heart disease
Very Poor (301-400)	May cause respiratory illness to the people on prolonged exposure. Effect may be more pronounced in people with lung and heart diseases
Severe (401 -500)	May cause respiratory impact even on healthy people and serious health impacts on people with lung/ heart disease. The health impacts may be experienced even during light physical activity

(Source: Ministry of Environment, Forest and Climate Change)

Literature Review

The issue of air pollution in urban India has been widely researched in terms of its impact on human health, environment and sustainability of urban life. Studies have indicated that some of the leading pollutants that cause negative health effects including respiratory illnesses to cardiovascular diseases are particulate matter (PM10 and PM2.5), nitrogen dioxide (NO_2), and sulfur dioxide (SO_2) (WHO, 2018). The impact is aggravated in fast growing cities where industrialization, motorization, and construction work content with the lack of regulations and insufficiency of infrastructural systems (Gupta et al., 2020).

Ambient Air Quality in Medium-Sized Indian Cities

Researchers have focused their studies on Air Quality of megacities such as Delhi, Mumbai, Bangalore, etc. while cities such as Kolhapur have remained under-researched until recently despite having equally serious or even more problematic pollution issues (Sharma and Kumar, 2021). It is also observed that in such cities, there is often lack of continuous monitoring system and complete emissions inventories, which result in small-scale, single-faceted research instead of coordinated air quality measurements (CPCB, 2023).

Early Air Quality Studies in Kolhapur

One of the first systematic studies of ambient air quality in Kolhapur, by Mangalekar et al. (2015), reported high levels of suspended particulate matter (SPM) and respirable suspended particulate matter (RSPM, which is now synonymous with PM10 and PM2.5) with high levels of suspension suspended particles observed especially in densely populated commercial and traffic-prone regions, including Dabholkar Corner and Mahadwar Road. Their results showed that there were repeated surpassing of the limits set by the Central Pollution Control Board (CPCB), especially in the dry post-monsoon and winter seasons, which highlights seasonal effects on the level of air pollution.

The trends shown by Mangalekar et al. were confirmed in subsequent monitoring done by Bhosale et al. in 2022-23. Further, Bhosale et al. extended their analysis to source apportionment, which revealed that the greatest contributions of PM10 was attributed to vehicular emissions and road dust. The study mentioned that over 40% of coarse particulate pollution was due to two-wheelers and diesel vehicles, along with significant contribution by road dust arising from unpaved surfaces, construction sites, and loose aggregates. (Bhosale, 2023)

Source Apportionment and Emission Inventories

In the comprehensive source apportionment and emission inventory report published by Maharashtra Pollution Control Board (MPCB) in 2022 helped in providing more clarity about Kolhapur's pollution. This report in a way endorsed the findings of previous studies and also confirmed that pollution by vehicles and suspended road dust particles together contributed more than 70% to the PM10 levels in major areas in the city. This report also observed that even small and medium scale industries along with burning of bio mass also played a role in polluting the city's air.

The report also highlighted the role of seasonal activities like agricultural residue burning, and open waste burning in the peri-urban regions which are episodic but result in acute pollution spikes that severely deteriorate the quality of air in the winter and post-monsoon months (MPCB, 2022; CPCB, 2023).

Meteorological Influences on Air Quality

Specific studies undertaken in Kolhapur and in the western region of Maharashtra reveal that regional meteorology has some impact on the dispersion of pollutants. The particulate concentrations are reduced due to rainfall in the period June to September, while low speeds and inversion of temperature during November to February restrict vertical mixing, increasing the concentration of pollutants at the ground level (Rao et al., 2019)

National Clean Air Programme (NCAP) and Policy Context

In 2019, the Government of India introduced National Clean Air Programme (NCAP) to address the rising air pollution crisis. The primary goal of this program was to initiate policies to reduce the particulate matter by around 20% to 30% by 2024 as compared to 2017 levels in 131 non-attainment cities, including Kolhapur (MoEFCC, 2019). The focus of the program was on exercising efforts in controlling the sector –specific source by regular monitoring, formulating regulation and creating awareness among the public.

According to the NCAP guidance, the Environment Plan developed for Kolhapur's District identified vehicular emissions, road dust, industrial emissions, and burning practices as priority sectors, for which strategies such as mechanized street sweeping, vehicle fitness programs, and enhanced industrial pollution controls were suggested. However, recent evaluations of NCAP implementation indicated the difficulties in the institutional capacity, the rigour of enforcement, citizen engagement, and monitoring density, which restrict the noticeable improvements in local air quality, including Kolhapur (Singh et al., 2022; CPCB, 2023).

Research Gap

There are limitations in the temporal scope in the existing studies. These studies have concentrated on specific pollutants or sectors without considering the context of spatial, seasonal, and sectoral variability. Further, there is lack of combined multi -year studies specifically for Kolhapur city that could connect the long-term ambient air quality trends along-with emission source dynamics and policy impacts.

The changing landscape of the urban Kolhapur characterized by the rising construction, developing vehicular growth, changing industrial and agricultural practices requires constant updated analysis to inform the relevant policymakers. In addition, there is a dearth of information on PM2.5 and gaseous pollutants, which restricts the knowledge about the exposure of finer particulate matter and associated health hazards.

Research Objectives

General Objective

- To empirically examine and assess the causes of air quality deterioration in Kolhapur city over the past five years (2021–2025).

Specific Objectives

- To examine recent temporal trends in PM10, PM2.5, NO_2, and SO_2 concentrations at key monitoring stations in Kolhapur.
- To combine source apportionment and emission inventory results to measure the proportionate contributions of key sectors (transport, road dust, industry, domestic fuel, biomass burning).
- To investigate the seasonal and spatial differences in pollutant levels across traffic, industrial, and background sites.
- To review NCAP and district-level action plans for Kolhapur and assess their alignment with empirically identified drivers.
- To recommend specific evidence-based measures for improving the quality of air in short to medium term.

Research Methodology

Data:

This study is based on secondary data and document analysis.

Methods

- Descriptive statistics to summarize concentration of pollutant by year, season and location.
- Qualitative analysis of source apportionment data to assign sectoral contributions.
- Comparative analysis between observed exceedances and the sectoral measures outlined in NCAP and district plans.
- Interpretation is contextualized within established knowledge of meteorological effects on the quality of air in Western Maharashtra.

Data Analysis and Interpretation

Trend in Particulate Matter (2021–2025)

Recent analyses of MPCB and emission inventory show that PM10 has been exceeding the National Ambience Air Quality Standards (NAAQS) threshold (annual 100 $\mu g/m^3$) at key urban locations for much of the 2021-2025 period. Locations with high traffic like the Dabholkar Corner and Mahadwar Road continue to record the highest concentration, while comparatively greener areas and less congested areas like Shivaji University show low, but alarming levels of particulates.

Kolhapur is classified as a non - attainment city due to exceedance of PM10 factor reported in the District Environment Plan, This confirms that PM10 is not an infrequent phenomenon but a consistent issue. Less spatially-dense PM2.5 data exhibit similar patterns and emphasize the role of combustion-related sources in driving fine particulates.

Sectoral Source Contributions

According to the source apportionment conducted by Bhosale and MPCB's study of PM10 shows that the road dust and exhaust of vehicles are the largest contributors to PM10 emissions in Kolhapur. The road dust constitutes re-suspension of particles from paved and unpaved roads and construction debris. The findings of the emission inventory suggest that higher percentage of emissions is caused dues to re-suspended dust as compared to tailpipe emissions of vehicles highlighting the importance of street sweeping and Construction and Demolition waste management.

Approximately three lakh vehicles with a high proportion of two-wheelers contribute both coarse and fine particulate matter as well as high loads of NO2, especially in congested corridors. Further, the industrial sources contribute the localized yet significant contribution of PM10 and gaseous pollutants released in industrial estates, especially where stack emission controls and fuel quality are inadequate.

Burning of Biomass and open waste in peri-urban and rural suburbs are recognized as important seasonal contributors. Even though their contribution to PM10 per annum may be less than transport and dust, they still cause acute short term spikes and contribute to secondary particulate formation.

Seasonal and Spatial Patterns
The results of the recent data are in line with the previous studies which revealed that pollutant concentrations in Kolhapur are lowest during the monsoon months when wet deposition is high due to rainfall, and when dust re-suspension is suppressed by soil moisture. While in the post monsoon and winter seasons there is increase in PM10 and PM2.5 on account of lower mixing heights and temperature inversions common to the area. Spatially, it is the commercial business areas and traffic junctions that display the highest particulate levels followed by industrial estates and finally the greener residential and suburban and peri-urban areas.

Policy Alignment and Gaps
The District Environment Plan of NCAP and Kolhapur focus on the control of road dust, better Construction and Demolition waste management, better public transport, better traffic management, and industrial emission control. These areas of focus are reasonably aligned with the major sources identified by emission inventories and source apportionment, which implies conceptual compatibility.

Non-compliance with PM10 and non-compliance status in the past five years however reflect weakness in areas of implementation such as limited coverage and frequency of mechanized street sweeping, partial execution of construction dust norms, incomplete Construction and Demolition waste processing infrastructure as well as capacity limitations in enforcing industrial emission standards. Moreover, the limited density of continuous air quality monitoring stations makes it difficult to track intervention effects on a fine scale.

Discussion,
This analysis shows that the decline in air quality in Kolhapur over the past five years is not caused because of one dominant factor, but has arisen due to an interconnected network of sources of emissions and enabling conditions. The accelerated growth of vehicles and the persistent road and construction dust implies that there is a problem with the planning of urban transport and land-use. Additional particulate loads arise due to industrial emissions and burning of biomass, which in unfavorable weather conditions push the level of pollutants beyond NAAQS.

The fact that the sources identified are very close to the sectors targeted under NCAP is an indication that the main policy framework is towards the correct direction. The main difficulty lies in scaling up, coordinating, and sustaining of implementation of these measures at the city level, especially on road dust control, Construction and Demolition waste management, rigorous enforcement of the industrial standards and behavior change to prevent open burning.

From the research perspective the past five years stress the importance of improving monitoring determination (both spatial and temporal) and integration of local health data so as to directly co-relate exposure with outcomes in Kolhapur. The local institutions and technical capacity needs to be strengthened for translating emission inventories and action plans into measurable air quality gains.

Conclusion
The findings of the imperial study reveals that the deterioration of air quality of Kolhapur in the last five years has been primarily driven by PM10 pollution associated with road dust, vehicular emissions, industrial activity, and biomass and waste burning. Persistent exceedance of national standards, particularly at high traffic junctions and commercial hotspots has been confirmed by the ambient monitoring data. Further, emission inventory and source apportionment studies have constantly identified road dust and transport as the leading contributors with industry and seasonal burning playing significant secondary roles.

Despite the fact that NCAP and other district-level plans focus on these areas, the present non-attainment status of Kolhapur has not changed, which indicates that the existing interventions are inadequate in terms of the scope or the enforcement. In order to reverse current trends, Kolhapur will have to focus on intensive management of road dust (mechanized sweeping and construction and demolition waste management), strengthen of public transport, vehicle emissions, modernization of industrial pollution control, and institutionalization of actions to stop open burning. Further data-driven approach to air quality management will be supported by expanded and high-quality monitoring and integrated health assessments.

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Biofertilizers in Crop Production and Stress Management for Sustainable Agriculture

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Abstract
With the increase in world population, the demography of humans is estimated to be exceeded and it has become a major challenge to provide an adequate amount of food, feed, and agricultural products majorly in developing countries. The use of chemical fertilizers causes the plant to grow efficiently and rapidly to meet the food demand. The drawbacks of using a higher quantity of chemical or synthetic fertilizers are environmental pollution, persistent changes in the soil ecology, physiochemical composition, decreasing agricultural productivity and cause several health hazards. Climatic factors are responsible for enhancing abiotic stress on crops, resulting in reduced agricultural productivity. There are various types of abiotic and biotic stress factors like soil salinity, drought, wind, improper temperature, heavy metals, waterlogging, and different weeds and phytopathogens like bacteria, viruses, fungi, and nematodes which attack plants, reducing crop productivity and quality. There is a shift toward the use of biofertilizers due to all these facts, which provide nutrition through natural processes like zinc, potassium and phosphorus solubilization, nitrogen fixation, production of hormones, siderophore, various hydrolytic enzymes and protect the plant from different plant pathogens and stress conditions. They provide the nutrition in adequate amount that is sufficient for healthy crop development to fulfill the demand of the increasing population worldwide, eco-friendly and economically convenient. This review will focus on biofertilizers and their mechanisms of action, role in crop productivity and in biotic/abiotic stress tolerance.

Keywords: Abiotic Stress, Biotic Stress, Biofertilizers, Crop Productivity, Plant-Root Interaction

Introduction

The world population will reach 9 billion by 2050 in accordance with Food and Agricultural Organization; as a result, there should be an enhancement in crop yield to meet the food demand. Soil is an important source of food production in human lifespan. In the last decades, due to the increase in agricultural practices such as pesticides and chemical fertilizers it has been degraded at a universal scale and causes lower fertility due to loss in biodiversity, water retention, and disturbance in biogeochemical cycles. Soil health and plant productivity are severely influenced by numerous interactions among plant, soil, and microorganisms. Soil microbes cooperate with one another and also with plant roots in numerous means providing a wide variety of essential acts which are valuable for sustaining the ecological balance in soil. Plant microbial interactions are positive if they improve plant survival, nutritional status, and crop productivity and they are negative if they reduce plant growth. The application of biofertilizers can be a probable approach to improve soil microbial status that stimulates the natural soil microbiota therefore influencing nutrient accessibility and decomposition of organic matter. It was observed that the supply of biofertilizers in apricot modifies the microbial composition and degradation process which could be efficient in nutrient cycles in soil under field conditions. The capability of biofertilizers to form a high-level microbial diversity in soil may outcome better crop productivity for sustainable agriculture.

Nutrients are required by every living creature in this world. A total of 17 essential plant nutrients are mandatory for the proper development of plants. These 17 nutrients are divided into three classes based on the amount required such as major nutrients (carbon, hydrogen, oxygen, nitrogen, phosphorus, and potassium), minor nutrients such as sulfur, calcium, and magnesium, and micronutrients (nickel, zinc, molybdenum, manganese, iron, copper, chlorine, and boron). The plant takes up oxygen, hydrogen, and carbon from air and water, but the other nutrients are taken from soils in inorganic forms. Biofertilizer or biological fertilizer is a material that contains living or dormant microorganisms that colonize the rhizosphere or present inside the plants and directly or indirectly promotes the growth of plants by supplying nutrition. Microorganisms present in soil used as biofertilizers can mobilize the nutrient from soil and convert them into a usable form from unusable form through biological processes like nitrogen fixation, phosphorus solubilization, zinc solubilization, siderophores production, and producing plant growth-

promoting substances. Biofertilizers are applied to seed, root, soil, or by the foliar spray to enhance the microbial activity through their multiplication which then mobilizes the nutrients to target plants which remarkably improved the soil fertility and sooner increases the crop health and production.

Biotic stress is responsible to damage plants by pathogenic organisms like bacteria, fungi, viruses, parasites, and insects and by other harmful plants. They lead to declining the crop productivity by causing diseases such as vascular wilts, leaf spots, cankers, nutrient deficiency, systematic damage, chlorosis, stunting and reduce plant vigor, ultimately causing the death of the plants. The indirect mechanisms include the induction of acquired systematic resistance, plant pathogen molecular patterns (PAMPs) which in turn trigger the immunity and plant resistance proteins. Microorganisms solubilize the phosphorus and zinc, fixing the nitrogen and other macro- and micronutrients which promote the growth of the plants under biotic stress condition by providing nutrition. They also enhance the stress resistance in plants by expressing the gene of phytohormones and stress-related metabolite. When pathogen attacks, the plant produces various compounds within the tissues that lead to the activation of defense mechanisms inside the plants such as induced systematic resistance, peroxidases, phenylalanine ammonia-lyase, polyphenol oxidase, and hypersensitivity.

Climatic change is one of the major factors for enhancing abiotic stress on crops which results in reduced crop productivity. Climatic-related abiotic stresses included drought, waterlogging, excessive heat, and soil-related abiotic stresses are fertility, heavy metals, and salinity; all these are responsible for the poor yields of crops around the whole globe. There is less water available to plants during drought conditions, and biofertilizers have the potential to produce cytokinin, gibberellins, abscisic acid, and IAA, which cause the plant to increase its growth, root length, total surface area, and the formation of root hairs and lateral roots, which increases water absorption from water-deficient soil. Pollutants released from industry without any further operation if released in the environment then they cause the accumulation of heavy metals such as copper, lead, nickel, zinc, etc which have detrimental effects on the plants and animals. These heavy metals are removed from the environment by micro- and macro-nutrient solubilizing and mineralizing microorganisms. Heat stress causes cellular changes like production of reactive oxygen species, reduction in cell turgidity, reduction in water uptake, reduction in growth of plants, ultimately leading to death of plant by showing initial symptoms like leaf senescence, damages to chloroplast, wilting of plant, and chlorosis, whereas low temperature causes the inactivation of protein and reduces the cell membrane fluidity leading to increases in photosynthesis, imbalance of water transport. All these temperature-related stresses coped up by plants after the accumulation of the hydrophilic and osmolytes protein.

Literature review:

- biofertilizers — microbial inoculants such as rhizobia, Azotobacter, Bacillus, Pseudomonas, arbuscular mycorrhizal fungi (AMF) and microalgae — in sustaining crop productivity while reducing chemical inputs. Reviews and meta-analyses report consistent yield and nutrient-use efficiency improvements when biofertilizers are integrated into cropping systems, and they document substantial potential for reducing synthetic N and P fertilizer requirements (Chaudhary, 2022; Santos, 2024).

- Mechanistically, recent work has clarified how biofertilizers confer both nutritional and stress-protective benefits. Key mechanisms include biological nitrogen fixation, solubilization/mobilization of phosphorus and potassium, production of siderophores, secretion of phytohormones (e.g., IAA), synthesis of ACC-deaminase (which lowers stress ethylene), antioxidant enzyme induction, and production of lytic compounds that suppress pathogens. These multifunctional traits enable microbes to improve nutrient availability and strengthen plant resilience to abiotic stresses (drought, salinity, temperature extremes, heavy metals) and biotic stresses (pathogens, nematodes). The importance of ISR (induced systemic resistance) and microbe-triggered modulation of plant signalling pathways has been emphasised in several recent reviews (de Andrade et al., 2023; Chaudhary, 2022; Salwan et al., 2023).

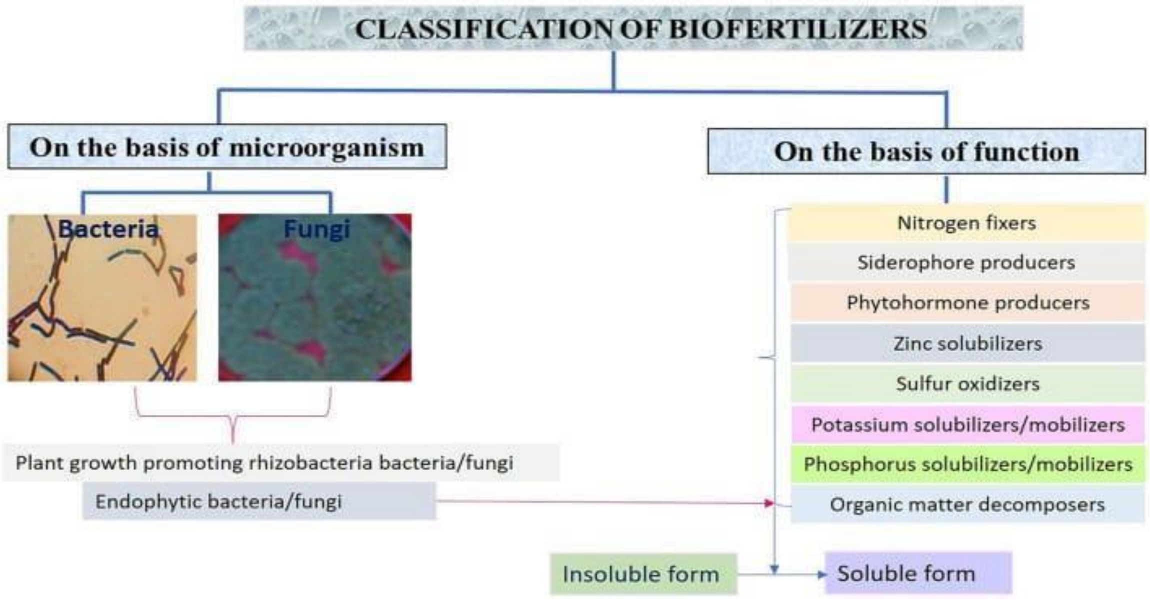
- Applied studies from 2020–2024 provide crop-level evidence: inoculation with PGPR and AMF improved drought tolerance through enhanced root growth and osmotic adjustment, while certain Bacillus and Pseudomonas strains reduced salt injury by maintaining K^+/Na^+ balance and producing osmoprotectants. Field and pot trials also demonstrate reduction of heavy-metal uptake via microbial biosorption and immobilization mechanisms. Such applied reports underscore that targeted biofertilizer use can measurably enhance yield stability under stress conditions (Samantaray et al., 2024; Zhao, 2024).

- Despite promising results, contemporary literature repeatedly flags limitations and research gaps. These include variable field efficacy due to soil, climate and crop interactions; inconsistent regulatory frameworks and quality standards across regions; scale-up challenges for low-cost, high-viability products; and the need for long-term ecological assessments of introduced strains. Several authors call for standardized efficacy testing, genomic-guided strain selection, and integrated management packages (biofertilizer + organic amendments + best agronomy) to achieve reliable outcomes at scale (Chaudhary, 2022; Santos, 2024; Zhao, 2024).

Biofertilizers:

Biofertilizer refers to the use of microorganisms to meet nutritional needs, whereas in other countries, the term microbial bioinoculant is used. Biofertilizers are bio-based organic fertilizers that either could be from plant or animal sources or from living or dormant microbial cells that have the potential to improve the bioavailability and bioaccessibility of nutrient uptake in plants. biofertilizers are properly defined as “the preparations containing live microbes that help in enhancing soil fertility by fixing atmospheric nitrogen, solubilizing phosphorus or decomposing organic wastes or by elevating plant growth through the production of growth hormones with their biological activities. Biofertilizers are generally applied in solid or dry forms, which are prepared after packing on suitable carriers such as clay minerals, rice bran, peat, lignite, wheat bran, humus, and wood charcoal. Carriers increase the shelf life and enable the easy handling of microbial inoculants. The benefits of biofertilizers include low cost, enhanced nutrient availability, improved soil fertility, protect plants from soil-borne pathogens, sustainable agricultural production, enhanced biotic and abiotic stress tolerance, promote phytohormone production, improve soil health, causing less environmental pollution, and its continued use improves the fertility of soil considerably. Based on the source and raw material, global biofertilizer is marketed under two major categories like organic residue-based biofertilizer and microorganisms-based biofertilizer. Green manure, crop residues, treated sewage sludge, and farmyard manure are generally organic-based biofertilizers. While on the contrary, microorganism-based biofertilizers contain beneficial microorganisms like bacteria, fungi, and algae. Directly or indirectly, these biofertilizers mediate the performance of plant growth. Direct mechanisms that act upon plants directly include nitrogen fixation, phosphate solubilization, micronutrient solubilization, and the production of phytohormones. The indirect mechanism generally protects the plant from the deleterious effect of the pathogens by releasing lytic enzymes, antibiotics, siderophores, and cyanide production.

Figure 1:



Types of biofertilizers and their role in crop production and soil health maintenance

Biofertilizers are classified based on microorganisms such as bacteria and fungi and function of the biofertilizers

- **Nitrogen-fixing biofertilizers**

  Nitrogen is the vital macro-nutrient essential by plants because it improves the growth of the shoot system, helps in reproduction, is a constituent of chlorophyll responsible for the deep green color, and also increases the size of the grains. Although the nitrogen content in the atmosphere is 78% by a mass fraction, dinitrogen contains triple bonds and is an unavailable form of nitrogen present in the air for the plants. Dinitrogen should be first converted into soluble non-toxic form ammonia by the diazotrophs through the biological process of nitrogen fixations. This ammonia is then converted to the nitrite and nitrate by the ammonia-oxidizing bacteria and by nitrifying bacteria, respectively. The unused nitrate is converted to the atmospheric nitrogen in the deeper soil horizons through the process of denitrification which will then escape to the atmosphere as dinitrogen gas. This is the typical path of the nitrogen cycle

- **Symbiotic nitrogen-fixing microbes**

  In the process of symbiosis, macro-symbiont is the plant and microsymbionts are the prokaryotic bacteria. Rhizobium and legume symbiosis is one of the most studied mutualistic relationships between plant root nodules and nitrogen-fixing microorganisms. Mutualistic relationships are initiated when the plant began to secrete the flavonoids and iso-flavonoids in its rhizosphere, where it is recognized by Rhizobium. It started to do infection by differentiating root hairs, developing infection thread up to the root hair cell where infectious thread releases all its bacteria in the cytoplasmic region. Then, bacterial cell are terminally differentiated into the bacteroides, and the further development of bacteroides leads to the formation of symbiosome which is the site of nitrogen fixation. This atmospheric nitrogen fixation inside the nodule is carried out by the nitrogenase enzyme. Examples include Rhizobium associated with leguminous plants, Frankia (actinomycetes) associated with non-leguminous plants. Azolla and the blue-green alga Anabaena azollae, and association of cyanobacteria with gymnosperms.Fixation of N helps to improve the soil fertility and crop productivity.

- **Free-living nitrogen-fixing bacteria**
  Mostly Azotobacter is studied because it is a free-living, non-symbiotic, and phototropic bacterium. Azotobacter chroococcum can be used as a biofertilizer because it has the potential to fix 10 mgN/g of carbon source supplied in-vitro. Plant hormones such as indole acetic acids, gibberellic acids, naphthalene acetic acid, and vitamin B complex are produced by Azotobacter. It inhibits the root pathogens while promoting root growth, helps in mineral uptake, and improves soil fertility.

- **Nitrogen-fixing bacteria**
  Spirillum was found associated with the roots of the grain which were also capable of fixing nitrogen. Azospirillum is gram-negative, non-nodulating, aerobic-associative nitrogen-fixing bacteria with plants having a C4 dicarboxylic pathway of photosynthesis, such as sugarcane, maize, sorghum, bajra, and cereals like wheat, rice, barley. They also produce cytokinin, gibberellins, and indole acetic acid, which aid in the uptake of N, P, and K and promote the growth of roots.

- **Phosphorus-solubilizing biofertilizers**
  Phosphorus is the second macro-nutrient that is responsible for limiting the growth of plants. It is an important constituent of organic and nucleic acids and is responsible for the synthesis of ATP and several amino acids. P helps in the nodulation process, amino acid synthesis, and proteins in leguminous plants. Soluble form of phosphorus is phosphate anion (orthophosphate), and their uptake is facilitated by rhizospheric microbes which help in plant nutrition. There are different microbes which can solubilize the remaining unavailable form of P into available form via organic acid production by bacteria which lowers the pH of the soil, leads to the dissolution of the phosphate compounds, and makes them available for the plant's nutrition.

- **Phosphorus-mobilizing biofertilizers**
  They are beneficial bacteria that effectively mobilize the soluble phosphorus and mineralization of the organic phosphorus compound, both are unavailable form of phosphorus. Bacillus, Pseudomonas, and Rhizobium are representative phosphorus- mobilizing microorganisms (PMB). Three different mechanisms have been reported for this process. First, PMB is releasing the phosphatases enzyme. Second, PMB is producing organic acids. The last one added PMB may interact symbiotically with the other fungal mycorrhiza which mobilizes the soluble phosphorus from distant places where plant roots cannot reach by absorbing soluble phosphate by hyphae. One of the major advantages of Arbuscular mycorrhiza is transporting both inorganic and organic forms of phosphorus to plants.

- **Sulfur-solubilizing biofertilizers**

- **Sulfur helps in chlorophyll formation, activation of a certain enzyme, amino acid formation, vitamin formation** and promotes nodulation, vital for the development of all plants. Sulfur solubilizers are also known as sulfur-oxidizing bacteria because they are transforming the most insoluble form of sulfur that is hydrogen sulfide (H_2S) into an available form of sulfur known as sulfate (SO_4^{-2}), and the reverse of this process is known assimilatory sulfate reduction which is mediated by sulfate-reducing bacteria. Sulfur transformation in the soil is primarily due to the microbial activity through the processes of mineralization, immobilization, oxidation, and reduction.

- **Zinc-solubilizing biofertilizers**
  Zinc is required during protein synthesis, DNA–protein interaction, growth hormone production, seed development, production of chlorophyll and protects plants from stress conditions. Insoluble forms of zinc are mostly ZnO, $Zn_3(PO_4)_2$, $ZnCO_3$, and metallic Zn. The usable form of zinc by the plant is divalent cations. Zinc-solubilizing fertilizers contain the zinc solubilization bacteria which produce the organic acids to solubilize the insoluble zinc to Zn^{+2}, thereby enhancing zinc uptake in plants.

- **Phytohormone-producing biofertilizers**

Plant hormone or phytohormone plays a substantial role in plant development, secreted by both plants and microorganisms. Plant hormone production is an important feature of the beneficial microbes which is producing the indole-3-acetic acids, gibberellins, cytokinin, etc. Auxin helped in the differentiation and division of plant cells. Cytokinin prevents the premature leaf senescence of plants. Abscisic acid is also identified as hormone which is produced by plants during stress conditions. Gibberellins are involved in seed germination, shoot elongation, flowering, and fruiting. These hormones are generally secreted by microorganisms under environmental stress conditions to protect the plants by modulating the phytohormone level inside the host plants.

- **Organic matter decomposer biofertilizers**
  Soil organic matter is a mixture of living organisms consisting of bacteria, fungi, and insects, and the non-living part which includes fresh organic residues or waste, the dead and decaying matter of living organisms is generally known as humus. In organic matter generally, cellulose, lignin, hemicellulose, chitin, and lipids are present which are degraded by microbes such as bacteria, actinomycetes, and fungi. The organic-matter-degrading organisms break down the SOM into simpler or inorganic from which they derive energy and carbon for their growth. Examples of bacteriainclude Bacillus subtilis and Pseudomonas fluorescens and of fungi include ectomycorrhizal fungi. Trichoderma spp. involved in the degradation of litter at a faster rate releases antimicrobial compounds, improves the physicochemical properties of soil, and improves microbial diversity.

- **Endophytic bacteria as biofertilizers**
  Mutualistic microorganisms that employ the whole or part of their life cycle inside the plant tissues are known as endophytes. Endophytes are of interest because they improve the nutritional requirements of the non-leguminous and leguminous plants by nitrogen fixation, phosphate solubilization, or by siderophores production. These bacteria have the potential to suppress pathogenic effects by activating the plant defense system.

- **Plant growth-promoting rhizobacteria**
  PGPR is used as biofertilizers; it represents the variation of soil bacteria that live in association with the rhizosphere, rhizoplane associated to root surface, and endophytes present inside the intercellular places. PGPRs are soil bacteria which increase the growth and enhance the tolerance of plants toward stress conditions. There are diverse mechanisms shown by PGPR which support the plant growth such as N2 fixation, macro- and micronutrient mineralization, secretion of exopolysaccharides, phytohormone production, siderophore, hydrogen cyanide to prevent the growth of phytopathogens, antibiotics, etc. Rhizobium lupini increased alfalfa growth and enhanced nutrient uptake efficiency. Application of biofertilizers such as Pseudomonas taiwanensis, Bacillus spp., and Pantoea agglomerans improved the maize growth, yield, and soil health parameters.

Role of biofertilizers in biotic stress management

The outbreak of plant diseases in nature necessitates sustainable agriculture with minimum use of agrochemicals. For a long time, the use of chemicals has posed a significant risk to the environment and the agricultural sector. Long-term use of pesticides, on the other hand, harms both plant/soil health and eventually leads to significant crop loss. Thus, effective and eco- friendly phytopathogen control strategies such as biofertilizers are required. The exploitation of potential biofertilizers as endophytes could be useful to improve crop plants from various bacterial and fungal diseases. Biological control of plant diseases occurs via destruction of pathogens via beneficial microbes such as Bacillus spp., Pseudomonas spp., Streptomyces, Pantoea spp., and several fungal spp. Such endosymbiont group of biocontrol agents being friendly, they not only colonize internal plant tissue but also protect host plant throughout its life cycle without causing any apparent damage.

Biofertilizers in the form of potential biocontrol agents represent a safe alternative to harmful chemicals like fertilizers, herbicides, pesticides, and insecticides. Consequently, the use of biofertilizers is receiving special attention for the management of phytopathogens that are comprised of bacteria, fungi, virus, aphids, and nematodes. Their ubiquitous nature and the ability to reside within plant tissues make them unique, showing multidimensional interactions within the host plant.

Role of biofertilizers in biotic stress tolerance

Category	Example	Role	Mechanism of Action
Nitrogen Fixers	Rhizobium, Azotobacter, Azospirillum	Protect plants from pathogen attacks and improve immunity Enhance nitrogen supply, trigger induced systemic resistance	Enhance nitrogen supply, trigger induced systemic resistance
Zinc Solubilizers	Bacillus, Pseudomonas	Reduce fungal and bacterial infection.	Increase zinc availability, enhance plant defense enzyme activity.
Sulfur Oxidizers	Thiobacillus	Suppress soil-borne fungal pathogens.	Produce sulfuric acid and other compounds toxic to pathogens
Phosphorus	Bacillus megaterium, Pseudomonas striata	Suppress root pathogens and nematodes.	Release organic acids and enzymes, improve Pnutrition and root defense
Organic Matter	Trichoderma, Aspergillus	Control soil-borne diseases.	Produce antibiotics, lytic enzymes, and compete with pathogens

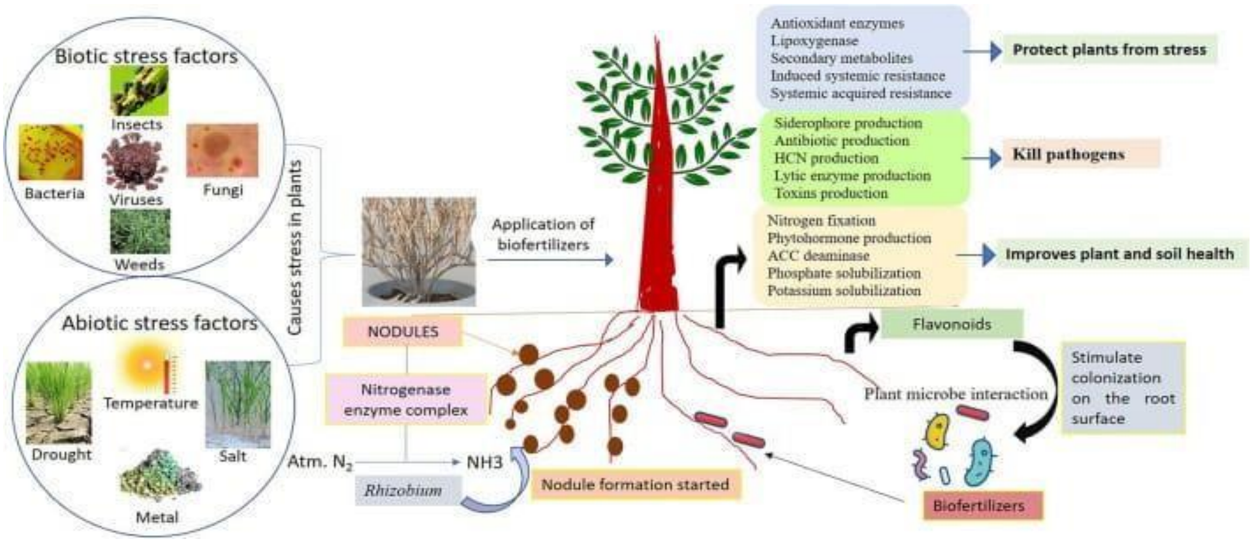
(Source – Primary data)

Role of biofertilizers in abiotic stress management

Climate change is one of the major reasons for the increasing abiotic stresses on the crops, which results in reducing the world's agriculture productivity. Abiotic stresses like drought, salinity, waterlogging, and excessive heat are responsible for the poor yield of crops. In recent years, the abiotic stress has increased so fast, because of the fluctuation of climates or climate change, and it has caused an unusual rise in the weather conditions and incidents, which is responsible for the substantial losses of crops around the globe. These abiotic stresses induce several physiological, biochemical, and morphological changes in plant that finally affect the economic yield of crop plants, and it was reported that the yield loss from abiotic stress is about 51–82%, which if continues will affect the goal of sustainable food production.

Biofertilizers as endophytes are found to have diverse associations with its host plant such as symbiotic, parasitic, and mutualistic and colonize plant tissues without causing any disease, thusbenefiting for plants. Endophytes may benefit from mutualistic associations as they obtain nutrients from the hosts, and they spread by host seed transmission. They are also able to enhance the nutrients uptake like nitrogen, magnesium, zinc, and phosphorus from soil and provide to the host plant for better growth and survival. It is well-identified that plant biofertilizers play a significant role in supporting the growth of crops under different abiotic stresses.

Figure 02



Role of biofertilizers for maintenance of crop productivity and soil health

Role of biofertilizers in abiotic stress tolerance

Abiotic stress factor	biofertilizers	Mechanism of action	Benefit to plants
Drought	Azospirillum, bacillus subtilis	Enhance root growth, improve water uptake	Improves drought tolerance, better water-use efficiency
Salinity stress	Azotobacter, mycorrhizal fungi	Osmolyte production, ion homeostasis regulation, exopolysaccharide secretion	Reduces salt toxicity, maintains plant growth
Temperature	Azospirillum	Production of heat- shock proteins, antioxidants, and protective metabolites	Protects cells from oxidative damage, stabilizes enzymes
Soil nutrient deficiency	Rhizobium, azotobacter	Nitrogen fixation, phosphate & potassium solubilization, phytohormone production	Enhances soil fertility and nutrient availability
Oxidative stress	Bacillus, pseudomonas	Antioxidant enzyme production (SOD, CAT, peroxidases), secondary metabolites	Protects plant cells from ROS (reactive oxygen species) damage

(Source – Primary data)

- Drought stress
  Drought is one of the most critical abiotic stresses that reduces water availability, photosynthesis, and crop productivity. Plants under drought stress often produce high amounts of ethylene, a stress hormone that inhibits growth. Biofertilizers such as Azospirillum and Bacillus subtilis help plants by producing ACC deaminase, an enzyme that lowers ethylene levels, thus reducing stress effects. Mycorrhizal fungi also play a key role by increasing root surface area, which enhances water absorption from deeper soil layers. Additionally, some microorganisms produce exopolysaccharides (EPS) that improve soil structure and water retention. As a result, biofertilizers improve water-use efficiency, root development, and overall plant tolerance to drought.

- Salt Stress (Salinity):
  Salinity stress occurs due to excessive accumulation of salts in soil, mainly sodium (Na^{+}) and chloride (Cl^{-}) ions, which cause osmotic stress and ion toxicity in plants. This leads to leaf burn, nutrient imbalance, and stunted growth. Biofertilizers such as Pseudomonas fluorescens, Azotobacter, and arbuscular mycorrhizal fungi help plants overcome salinity by producing osmoprotectants and antioxidants that protect plant cells. They also regulate ion uptake by reducing sodium absorption and maintaining a healthy potassium/sodium ratio. Some bacteria produce exopolysaccharides that bind salt ions, reducing their harmful effect on roots. These mechanisms allow plants to maintain chlorophyll content, photosynthetic efficiency, and normal growth under saline conditions.

- Temperature Stress:
  Extreme temperatures negatively affect plant metabolism, enzyme activity, and cell membrane stability. High temperatures can denature proteins and reduce grain filling, while low temperatures slow down metabolic processes and damage tissues. Biofertilizers such as Azospirillum, Pseudomonas, and certain cyanobacteria help plants withstand temperature fluctuations by producing heat-shock proteins, antioxidants, and protective secondary metabolites. These compounds reduce oxidative damage and stabilize cellular structures. Through these protective mechanisms, biofertilizers enhance plant resilience against both heat and cold stress, ensuring better survival and productivity in adverse climates.

- Heavy Metal Stress:
  Heavy metal contamination of soil due to industrial activities and fertilizers is a major challenge for agriculture, as metals like cadmium (Cd), lead (Pb), and zinc (Zn) are toxic to plants. They inhibit enzyme activity, reduce nutrient uptake, and lead to poor plant growth. Biofertilizers such as Pseudomonas putida, Rhizobium, and mycorrhizal fungi mitigate this stress by producing siderophores, organic acids, and chelating agents that bind heavy metals and reduce their availability to plants. Some microorganisms also immobilize or transform metals into less toxic forms through biosorption

and bioaccumulation. This reduces heavy metal toxicity, improves nutrient absorption, and enhances plant tolerance in contaminated soils.

- Soil Nutrient Deficiency:
  Nutrient deficiency is another abiotic stress that reduces crop yield and soil fertility. Biofertilizers such as Rhizobium, Azotobacter, phosphate solubilizing bacteria (PSB), and potassium solubilizers play a crucial role in nutrient cycling. They fix atmospheric nitrogen, solubilize insoluble phosphorus and potassium, and release phytohormones that stimulate root growth. This ensures continuous nutrient availability in the soil, strengthens plants, and reduces stress caused by poor soil fertility.

Conclusion:

Agriculture systems have to face the task of food production, stress management, and dependency on agrochemicals. The presence of pest and pathogen in crops causes decrease in crop yield and heavy crop losses every year. The occurrence of abiotic stresses due to the change in climatic conditions leads to difficult challenge to crop production worldwide. Different effective approaches should be employed to reduce crop output loss and control diseases. Hence, the necessity to implement the eco-friendly approaches such as biofertilizers is of great importance for sustainable agriculture. The application of biofertilizers not only improves plant heath parameters but also enhances the crop productivity, soil health and protects from stress environment. More research has been focused on physiological and molecular aspects under different conditions with different crops using biofertilizers under field conditions.

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Treatment and Management of Dairy Wastewater Reference is Gokul Dairy, Kolhapur

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Abstract
Dairy industries generate large volumes of wastewater that contain high levels of organic matter, nutrients, suspended solids, and fats. Untreated discharge can cause severe environmental problems, including water pollution and ecosystem damage. This study explores various treatment methods for dairy wastewater, evaluates their effectiveness, and provides suggestions for efficient and sustainable wastewater management. Both conventional and advanced treatment methods are discussed, with a focus on biological, physicochemical, and hybrid techniques. Key findings highlight the need for cost-effective, energy-efficient, and eco- friendly solutions for small- and medium-scale dairy farms.
Like all wastes produced by a production plant, dairy wastewater needs to be treated before it is discharged into water bodies. Owing to their composition and organic matter content, biological treatments are emphasised and, currently, activated sludge is one of the mast used processes. This treatment, completed by other unitary operations, achieves the quality levels required for the discharge. However, dairy wastewater has interesting potentialities. Its unique composition can support energy production and its treatment, under some conditions, can allow the recovery of water for its reuse. Different technologies are currently available to accomplish these objectives: anaerobic reactor to treat carbon pollution and producing biogas, membrane bioreactor and membrane filtration for treating and producing water for reuse. Some dairy plants. already use these technologies and their feedbacks are positives.

Keywords: wastewater treatment, dairy industry, anaerobic reactor, membrane bioreactor, membrane filtration, water reuse, biogas production.

Introduction

The dairy industry is a significant part of the global food sector, contributing substantially to economic development and food security. However, it also poses environmental challenges due to the high volume and pollutant load of its wastewater. Dairy wastewater is primarily composed of milk residues, detergents, sanitizers, and other processing chemicals. If not treated properly, it can contaminate water bodies, harm aquatic life, and affect public health. This paper aims to provide an in-depth review of current treatment technologies, identify gaps, and suggest feasible solutions for sustainable dairy wastewater management.
The demand for milk and dairy products has increased significantly worldwide, leading to a rise in the number of dairy industries. Dairy waste management is crucial to minimize environmental harm by handling and disposing of byproducts effectively. Dairy wastewater, a byproduct from milk processing, contains high organic content such as lactose, proteins, whey, and salts. If discharged untreated, these can cause severe environmental damage.

In India, the dairy sector has grown rapidly and has become one of the largest milk producers globally. However, the dairy industry also contributes heavily to pollution due to the high organic load in wastewater, which necessitates advanced treatment methods. The goal of dairy waste management is to separate valuable components like lactose and protein from wastewater using technologies like ultrafiltration.

Milk and Milk Products have to been considered to be an important nutritional food because they are good sources of proteins, vitamins and calcium. The dairy sector in India has shown remarkable development in past decade and India has now become one of the largest producers of milk and value added milk products in the world. The dairy sector has developed through co-operatives in many parts of the State. During 1997-1998, the state had 60 milk processing plants with an aggregate processing capacity of 5.8 millions liters per day. In addition to this processing plants, 123 government and 33 co-operatives milk chilling centers operate in the state.

Dairy is considered to be one of the most important agriculture based industry in Indian scenario but despite of this fact dairy industry is also one of the most polluting industries in terms of the organic content in dairy effluent. This effluent contains a high concentration of organic matter mainly lactose, protein, whey, and mineral salts. They can be harmful to the environment, if discharged directly with the other liquid effluents from the dairy industry. It requires multistage processing before its discharge Additionally, the milk components present in the effluent possess large applications in food, chemical and drug industry. In this study, separation and recovery of components from dairy effluent was investigated. The Polysulfone (PSF) membrane based ultrafiltration process was adopted to separate lactose and protein with high yield and purity. The quantitative analysis were done for the recovery of the milk components from the effluent and it was observed that upto 90% of the lactose recovery could be achieved using the advanced separation technology.

A large amount of effluent is generated during the processing of milk in dairy . This Effluent is characterized by their relatively increased temperature, high organic content and wide pH range, which requires special purification in order to eliminate or reduce environmental damage. Conventionally it is done by the distructive methods like aerobic or anaerobic digestion . This leads to loss of nutritional components like proteins and lactose from the effluent. The effluent is characterized by high biological oxygen demand and chemical oxygen demand concentrations. It decomposed rapidly and depletes the dissolved oxygen level of the receiving streams immediately resulting in release of strong foul odour due to nuisance condition. Thus it is highly necessary to treat the effluent before its discharge. On the other hands the components from this effluent possess very high nutritional, food and drug value. Hence their recovery is highly advisable.

Dairy wastewater is a byproduct generated during the processing of milk and other dairy products. When milk is transformed into cheese, yogurt, or butter, water is used in various stages—cleaning, cooling, and even direct incorporation into the products. However, this water doesn’t exit the process as it entered; it becomes dairy wastewater. Laden with organic materials, chemicals, and residues. Therefore, it isn’t something you can simply pour back into nature without consequences to aquatic life and even human health.

Literature Review

Moodley et al. (2024) – Enzyme-based Anaerobic Digestion

Used enzyme-producing microbes to pre-treat dairy wastewater, improving biogas yield and organic removal. Found effective but cost-intensive.

Gavlak et al. (2024) – Mobile Bed Membrane Bioreactors

Improved traditional MBRs by adding mobile beds. Achieved >98% COD removal and better membrane performance. Reduced cleaning needs.

Shapiro Ellis et al. (2025) – Nutrient Recovery with Biochar

Tested biochar to recover nitrogen and phosphorus from dairy wastewater. Showed effective nutrient adsorption and potential for reuse.

Kanagam & Rajasekaran (2023) – Algal (Phycoremediation) Treatment

Applied microalgae to treat dairy effluents. Achieved good nutrient and BOD/COD removal. Also generated usable algal biomass.

EAOPs Review (2024) – Electrochemical Oxidation Methods

Reviewed electro-Fenton, photo-electro-Fenton, etc. Effective in removing tough pollutants. High energy and chemical costs limit scale-up.

Rajeshwari et al. (2000) – Anaerobic Treatment Systems

Investigated anaerobic digestion (especially UASB reactors) for high-strength industrial wastewater including dairy effluents. Reported over 80% BOD and COD removal with biogas recovery. Recommended anaerobic pre-treatment followed by polishing steps for best results.

Kushwaha, Srivastava & Mall (2011) – Integrated Treatment Approaches

Reviewed biological and physico-chemical treatment methods. Highlighted the effectiveness of combined treatments (e.g., coagulation followed by aerobic biological treatment).Identified limitations of conventional treatments in removing color, odor, and nutrients.

Cosenza et al. (2013) – Membrane Bioreactors (MBRs)

MBRs demonstrated superior pollutant removal and space efficiency. Issues like membrane fouling and operational cost remain challenges. Suitable for medium-to-large dairy plants with high wastewater volumes.

Prajapati et al. (2014) – Algal and Biological Treatment

Studied the use of microalgae for nutrient removal and biomass generation. Emphasized the dual benefit: wastewater treatment and resource recovery (biofuel, fertilizer).

Simate et al. (2011) – Advanced Oxidation and Electrochemical Techniques

Reviewed ozone, Fenton, UV, and electrocoagulation methods. Effective in removing refractory pollutants and disinfecting effluents. High energy and chemical costs limit large- scale use.

Objectives

The main objectives of this study on dairy waste management are:

1. To explore the concept of wastewater management in the dairy industry.
2. To analyze the role of Effluent Treatment Plants (ETP) in dairy waste management.
3. To understand the significance of dairy waste management in environmental protection.
4. To promote water reuse and recycling in dairy industries.

Research Methodology

The study is based on:
Exploratory Study: Investigating the current practices and challenges in dairy waste management.
Survey Research: Gathering data through surveys of dairy effluent treatment plant workers and industry experts.
Data collection methods include:

Primary Data: Direct observations and surveys in the dairy industry.

Secondary Data: Secondary data refers to information collected by someone else, often for different purposes, but is available for use. Existing literature, reports, and databases on dairy waste management.
Scope of Dairy Wastewater Management:

1. **Pollution Control:**
   Treating dairy wastewater helps prevent environmental pollution, especially of water bodies.
2. Water Reuse:
   Treated water can be reused for cleaning, gardening, or cooling systems, reducing freshwater demand.
3. Resource Recovery:
   Nutrients (like nitrogen and phosphorus) and by-products (like biogas from anaerobic digestion) can be recovered.
4. Regulatory Compliance:
   Proper wastewater management helps dairy industries comply with environmental laws and avoid penalties.
5. Public Health Protection:
   Prevents contamination of drinking water sources and reduces risk of waterborne diseases.
6. Sustainable Operations:
   Supports eco-friendly practices and improves the sustainability of dairy industries.
7. Cost Savings:
   Long-term savings through water recycling, energy recovery, and reduced waste disposal fees.
8. Corporate Social Responsibility (CSR):
   Enhances the company's image by showing commitment to environmental protection.
   Effective dairy waste management is crucial due to the following reasons:

Environmental Protection: Improper waste disposal can lead to water pollution, soil contamination, and air pollution, harming ecosystems and public health.
Resource Recovery: Dairy waste contains valuable components such as organic matter, which can be used for biogas production and as fertilizers.
Economic Benefits: Efficient waste management reduces disposal costs and increases dairy operation profitability.
Pollution Control: Dairy wastewater is rich in nutrients, and untreated discharge can cause eutrophication in water bodies, depleting oxygen levels and affecting aquatic life.
Soil Protection: Wastewater high in BOD and COD can degrade soil fertility if used untreated for irrigation.
Odor and Aesthetic Issues: Untreated waste can cause foul smells and unsightly conditions, especially near dairy plants.

Technical Process
The technical process involves several stages:
Milk Reception: Chilling and testing for quality.
Pasteurization: Heating milk to 72°C for 15 seconds to kill harmful bacteria. Homogenization: Ensures uniform fat distribution.
Separation and Standardization: Separation of cream and adjustment of fat content. Product Manufacturing: Milk is converted into products like ghee, curd, and paneer. Packaging: Hygienic and tamper-proof packaging.
Effluent Treatment Plant

Effluent Treatment Plants (ETPs) play a crucial role in maintaining environmental compliance and sustainability at Gokul Dairy. The plant is designed to treat and safely discharge wastewater generated during the production of milk and other dairy products.

Nature and Characteristics of Dairy Effluent
High BOD: 1000–3000 mg/L High COD: 2000–5000 mg/L High TSS: 500–2000 mg/L Presence of fats, oils, and greases Wide pH range (4.5 to 9.0)
High levels of nitrogen, phosphates, and pathogens

Fig No.1 Sewage treatment plant

Stages of Effluent Treatment

A. Preliminary Treatment Screening: Removes large solids.
 Slag Removal Tank: Filters heavy solids.
 Fat Removal Tank: Uses bacteria for aerobic degradation.

B. Equalization Tank
 Buffers pH and flow rate to prevent shock loading.

C. Anaerobic Treatment (UASB) Reduces BOD/COD by 80–90% Produces biogas for energy use

D. Aerobic Treatment Retention Time: 18–20 hrs DO: 1–2 mg/L
 Uses stirrers, nutrients (urea, DAP)

E. Clarifier Removes sludge
Recycles or dries sludge

F. Tertiary Treatment
Final filtration, pH correction
Treated water reused for irrigation/gardening

Chemical Dosing and Monitoring
Chemicals: HCl/NaOH (pH), Alum/PAC (coagulants), Urea/DAP (microbial support) Monitoring: pH, BOD, COD, DO, TSS

Performance Metrics

Parameter	Raw Effluent	Treated	MPCB Norms
pH	5.0–7.5	6.5–7.8	5.5–9.0
BOD	2500 mg/L	20–30	≤30
COD	4500 mg/L	200–250	≤250
Oil & Grease	80–100 mg/L	5–10	≤10
TSS	1200 mg/L	50–100	≤100
TDS	2500–3500 mg/L	1800–2000	≤2100

Environmental & Economic Benefits

Biogas recovery helps in cutting energy costs by utilizing waste for energy generation. Water reuse is implemented for non-potable purposes, conserving freshwater resources. Treated sludge is used as fertilizer, thereby serving as manure and reducing waste.

The system ensures regulatory compliance by meeting MPCB norms.

Challenges and Recommendations

It is important to improve sludge management to enhance efficiency and reduce environmental impact.
Expanding membrane filtration can improve water quality and system performance.
There is a need to integrate automation and sensors for better monitoring and control of processes.
Regular training for ETP staff is recommended to ensure proper operation and maintenance.

Fig no. 2 Effluent treatment plant

Findings

- The Biochemical Oxygen Demand (BOD) was reduced from an average of ~2500 mg/L in raw effluent to ~25 mg/L in treated effluent, achieving a ~99% reduction, which is well within the MPCB limit of 30 mg/L.
- The Chemical Oxygen Demand (COD) showed a similar reduction from ~4500 mg/L to ~225 mg/L, again meeting the MPCB standard of 250 mg/L.
- Total Suspended Solids (TSS) dropped from ~1200 mg/L to ~75 mg/L, complying with the limit of 100 mg/L.
- pH levels were adjusted from an acidic range (5.0–7.5) to a neutral and acceptable range (6.5– 7.8), staying comfortably within the MPCB-prescribed range (5.5–9.0).
- All treated effluent parameters consistently complied with MPCB discharge standards on a daily basis, showing stable and efficient performance of the treatment plant.
- Daily monitoring data shows minimal fluctuation in performance, suggesting well-maintained operations, timely interventions, and effective treatment process management.
- The treatment process ensures that no untreated or non-compliant wastewater is released into the environment, supporting the dairy's commitment to sustainability and pollution control.

Suggestions / Recommendations

Automate Monitoring and Data Logging
Implement digital sensors and SCADA systems for real-time monitoring of key parameters like pH, BOD, COD, and flow rate to improve accuracy and reduce manual errors.

Conduct Periodic Efficiency Audits
Perform monthly or quarterly efficiency audits of the ETP to identify operational bottlenecks and ensure consistent compliance with MPCB norms.

Install Flow Equalization Tank (if not present)
A flow equalization tank can help manage fluctuations in wastewater volume, improving the consistency and effectiveness of treatment.

Regular Maintenance and Sludge Management
Schedule preventive maintenance of pumps, aerators, and filters.
Ensure proper sludge disposal or reuse, as sludge buildup can affect treatment efficiency and lead to odor issues.

Introduce Waste Minimization at Source
Encourage water-saving measures in dairy processes to reduce the load on the ETP. Segregate high-load wastewater (e.g., from cleaning processes) to allow targeted treatment.

Conclusion
Effective dairy waste management is essential for environmental protection, resource recovery, and cost savings in dairy industries. With growing milk production, the need for proper effluent treatment systems. Dairy wastewater poses a significant environmental challenge, especially in regions with intensive dairy farming. While several treatment technologies exist, their feasibility depends on scale, cost, and local conditions. An integrated and context-specific approach is essential for effective treatment. Investment in sustainable technologies, combined with regulatory support and education, can mitigate the environmental impact of dairy wastewater and promote a circular economy within the dairy sector.

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Biomedical Waste: Risk, Regulation and Responsible Management

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Abstract
Biomedical waste (BMW) refers to any solid or liquid waste generated during medical, laboratory, or research activities related to the diagnosis, treatment, or prevention of diseases. Unlike general waste, biomedical waste carries a high risk of infection and injury, posing serious threats to healthcare workers, patients, and the community. It includes human and animal body parts, laboratory cultures, used syringes and needles, expired medicines, soiled bandages, liquid waste, chemical residues and incineration ash. The primary sources of biomedical waste include hospitals, clinics, medical and veterinary colleges, blood banks, mortuaries, diagnostic laboratories, biotechnology institutions, and even home healthcare or funeral services. Hazardous chemicals and radioactive materials, although not infectious, also form an important part of biomedical waste and require proper disposal to prevent environmental contamination. According to the World Health Organization (WHO), approximately 10% of hospital waste is infectious, while around 5% is hazardous but non-infectious. WHO classifies biomedical waste into eight categories: general, pathological, radioactive, chemical, infectious, sharps, pharmaceutical and pressurized wastes. Proper classification is critical for safe handling, treatment, and disposal. In India, the management of biomedical waste is regulated under the Biomedical Waste (Management & Handling) Rules, 1998, with subsequent amendments. These rules specify waste categories, color-coded bins, labeling requirements, transportation procedures, treatment standards, and operational guidelines for systems like incinerators, autoclaves, and microwaves. Effective biomedical waste management involves segregation at the source, safe storage, transportation, treatment, and final disposal. Segregation is generally achieved using color-coded containers: yellow for infectious, pathological, chemical, and pharmaceutical waste; red for contaminated plastics; white for sharps; and blue for glassware or metallic waste. Treatment technologies include autoclaving, chemical disinfection, incineration, and microwaving, depending on the type of waste. Proper biomedical waste management is essential to protect public health, prevent environmental pollution, and ensure the safety of healthcare workers. With increasing healthcare activities, growing awareness, and technological advancements, effective management of biomedical waste remains a shared responsibility of governments, healthcare institutions, and individuals.

Keywords - Biomedical Waste, Color Coding, Autoclaving, Incineration, Sustainability, Waste Treatment, Hospital Waste, Safe Disposal.

Introduction

Biomedical waste refers to any waste that is generated during the diagnosis, treatment, or immunization of human beings or animals, as well as in related research activities or in the production and testing of biologicals. This type of waste can include sharps (like needles and scalpels), soiled bandages, disposable items, anatomical waste, body fluids, discarded medicines, and other chemical or microbiological waste.

Biomedical waste (BMW) is primarily produced in healthcare settings such as hospitals, clinics, research institutions, and laboratories. Due to its infectious nature, it poses a significant risk of infection to medical staff, support workers, patients, and the general environment if not managed properly.

Types of Occupational Hazards from BMW:

- Accidental cuts or punctures from contaminated sharps (e.g. needles, knives, scalpels).
- Contact with infectious materials such as used gloves, tubing, surgical waste, bedding, and dressings.
- Exposure to bodily fluids like blood, urine, stool, or pus—particularly during cleaning and waste-handling tasks.

Composition and Quantity of Waste:

- Approximately70–80% of hospital waste is general (non-hazardous).
- About20–30%ishazardousorinfectious, which requires special handling and disposal.
- Improper segregation can lead to contamination of the entire waste stream, increasing the risk of infection.
- According to NEERI (National Environmental Engineering Research Institute), healthcare facilities in India generate approximately 0.5–2.0 kg of biomedical waste per bed per day. Annually, this amounts to around 0.33 million tons of biomedical waste.

Typical Composition of Hospital Solid Waste:

- Infectious waste(including soiled dressings and tissues):30–35%
- Plastics:7–10%
- Disposablesyringes:0.3–0.5%
- Glasswaste:3–5%
- General waste(including food waste):40–45%

Categories of Infectious Waste from Hospitals

The following types of waste generated in hospitals are classified as infectious waste, due to their potential to spread infections:

1. Waste from Patients with Communicable Diseases (I)

   Any waste generated from the treatment of patients suffering from infectious diseases.
2. Laboratory Waste (I)

   Cultures and stocks of infectious agents from microbiology, pathology, and biotechnology labs. Associated biologicals used in diagnostic procedures.
3. Human Blood and Blood Products (I)

   Includes blood, serum, plasma, and other derivatives.
4. Pathological Waste (I)

   Tissues, organs, body parts, and body fluids from surgeries or autopsies.
5. Contaminated Sharps (I)

   Items such as hypodermic needles, syringes, Pasteur pipettes, scalpel blades, and broken glass.
6. Surgical and Autopsy Waste (I)

   Soiled dressings, sponges, surgical gloves, and lavage tubes.
7. Contaminated Laboratory Materials (I)

   Specimen containers, slides and cover slips, disposable gloves, dialysis units, and waste collected from floor sweepings in patient rooms (e.g., swabs, soil particles).
8. Radioactive Waste (R)

   Materials containing radionuclides used in diagnostics and therapeutic procedures.

Sources of generation:
Solid waste generated from different sources of the hospitals– Note- I: infectious disease
NI: non-infectious disease
R: radioactive waste
D:domestic waste

Major Sources of Health Care Waste
Healthcare waste is generated from a variety of medical and research settings, including:

1. Hospitals
2. Nursing Homes
3. Laboratories and Research Centers
4. Mortuaries and Autopsy Centers
5. Veterinary Hospitals and Animal Clinics
6. Animal Research and Testing Laboratories
7. Blood Banks and Blood Collection Services
8. Medical and Nursing Colleges

Importance of Waste Quantification

Quantitative estimation of infectious and non-infectious waste is crucial for proper biomedical waste management.

- Infectious waste is highly hazardous and can transmit diseases either directly or via vectors (like flies, rodents, etc.).
- Accurate data helps in planning safe collection, storage, treatment, and disposal systems.

➢ Categories

Part-1
SCHEDULEI[Seerules3(e),4(b),7(1),7(2),7(5),7(6)and8(2)]

Biomedical wastes categories and their segregation, collection, treatment, processing and disposal options

Category	Type of Waste	Type of Bag or Container to be used	Treatment and Disposal options
1	2	3	4
Yellow	a) Human Anatomical Waste: Human tissues, organs, body parts and fetus below the viability period (as per the Medical Termination of Pregnancy Act 1971, amended from time to time).	Yellow coloured non- chlorinated plastic bags	Incineration or Pla or deep burial*
	(b)Animal Anatomical Waste :Experimental animal carcasses, body parts, organs, tissues, including the waste generated from animals used in experiments or or testing in veterinary hospitals or colleges or animal houses.		
	(c)Soiled Waste: Items contaminated with blood, body fluids like dressings, plaster casts, cotton swabs and bags containing residual or discarded blood and blood components.		Incineration or Plasma Pyrolysis or deep burial* In absence waving/of facilities, autoclaving or micro above waving/ or micr -hydroclaving followed by shredding or mutilation or combination of sterilization and shredding. Treated waste to be sent for energy recovery.
	(d) Expired or Discarded Medicines: Pharmaceutical waste like antibiotics, cytotoxic drugs including all items contaminated with cytotoxic drugs along with glass or plastic ampoules, vials etc	Yellow coloured non- chlorinated plastic bags or containers	Expired `cytotoxic drugs and items contaminated with cytotoxic drugs to be returned back to the manufacturer or supplier for incineration at temperature >1200 0C or to common bio-medical waste treatment facility or hazardous waste treatment, storage and disposal facility for incineration at >12000C Or Encapsulation or Plasma Pyrolysis at >12000C All other discarded medicines shall be either sent back to manufacturer or disposed by incineration.

	(e) Chemical Waste: Chemicals used in production of biological and used or discarded disinfectants.	Yellow coloured containers or non-chlorinated plastic bags	Disposed of by incineration or Plasma Pyrolysis or Encapsulation in hazardous waste treatment, storage and disposal facility
	(f) Chemical Liquid Waste : Liquid waste generated due to use of chemicals in production of biological and used or discarded disinfectants, Silver X-ray film developing liquid, discarded Formalin, infected secretions, aspirated body fluids, liquid laboratories and floor washings, cleaning, house-keeping and disinfecting activities etc.from	Separate collection system leading to effluent treatment system	After resource recovery, the chemical liquid waste shall be pre-treated before mixing with other wastewater. The combined discharge shall conform to the discharge norms given in Schedule-III.
	(g) Discarded linen, mattresses, beddings contaminated with blood or body fluid.	Non- chlorinated yellow plastic bags or suitable packing material	Non- chlorinated chemical disinfection followed by incineration or Plazma Pyrolysis or for energy recovery. In absence of above facilities, shredding or mutilation or combination of sterilization and shredding. Treated waste to be sent for energy recovery or incineration or Plazma Pyrolysis.
	(h) Microbiology, Biotechnology and other clinical laboratory waste: Blood bags, Laboratory cultures, stocks or specimens of micro-organisms, live or attenuated vaccines, human and animal cell cultures used in research, industrial laboratories, production of biological, residual toxins, dishes and devices used for cultures.	Auto clave safe plastic bags or containers	Pre-treat to sterilize with non chlorinated chemicals on- site as per National AIDS Control Organisation or World Health Organisation guidelines there after for Incineration.
Red	**Contaminated Waste** **(Recyclable)** (a) Wastes generated from disposable items such as tubing, bottles, intravenous tubes and sets, catheters, urine bags, syringes (without needles and *fixed needle syringes*) and vaccutainers with their needles cut) and gloves.	Red coloured non-chlorinated plastic bags or containers	Autoclaving or micro-waving/ hydroclaving followed by shredding or mutilation or combination of sterilization and shredding. Treated waste to be sent to registered or authorized recyclers or for energy recovery or plastics to diesel or fuel oil or for road making, whichever is possible. Plastic waste should not be sent to landfill sites.

White (Translucent)	**Waste sharps including Metals:** Needles, syringes with fixed needles, needles from needle tip cutter or burner, scalpels, blades, or any other contaminated sharp object that may cause puncture and cuts. This includes both used, discarded and contaminated metal sharps	Puncture proof,Leak proof, tamper proof containers	Autoclaving or Dry Heat Sterilization followed by shredding or mutilation or encapsulation in metal container or cement concrete; combination of shredding cum autoclaving; and sent for final disposal to iron foundries (having consent to operate from the State Pollution Control Boards or Pollution Control Committees) or sanitary landfill or designated concrete waste sharp pit.
Blue	**(a) Glassware:** Broken or discarded and contaminated glass including medicine vials and ampoules except those contaminated with cytotoxic wastes. **(b) Metallic Body Implants**	Cardboard boxes with blue colored marking Cardboard boxes with blue colored marking	Disinfection (by soaking the washed glass waste after cleaning with detergent and Sodium Hypochlorite treatment) or through autoclaving or microwaving or hydroclaving and then sent for recycling.

Segregation, Handling, Storage, Transportation Of Bio- Medical Waste

Handling :

- Proper handling of biomedical waste is essential for safety and infection control.
- Waste should be segregated immediately after generation into specific color-coded containers or bags, as per the type of waste.
- Containers should be emptied when they are three-quarters (¾) full to avoid spillage or overfilling.
- Special care must be taken to prevent needle-stick injuries and reduce the risk of infection.
- Biomedical waste must not be mixed with any other types of waste.
- During transportation, the waste should be handled carefully and not overloaded to ensure safe and hygienic disposal.

Storage :

- Every hospital or healthcare facility should designate a specific area within its premises for storing biomedical waste.
- The storage area must have an impermeable, hard-standing floor with proper drainage, making it easy to clean and disinfect.
- A water supply should be available nearby for cleaning purposes.
- The area should be easily accessible to the staff responsible for waste handling.
- The storage space must be lockable to prevent entry by unauthorized individuals.
- It should allow easy access for waste collection vehicles.
- The storage location should provide protection from direct sunlight.
- It must be inaccessible to animals, insects, and birds to avoid contamination.
- The area should be well-lit and have at least passive ventilation.
- It must not be located near food storage or preparation areas to prevent contamination risks.
- A supply of cleaning equipment, protective clothing, and waste bags or containers should be kept close to the storage area.
- Cytotoxic waste (e.g., chemotherapy waste) must be stored separately in a secure, designated location.

Transportation :

- Designated internal routes should be used for moving waste within the hospital to avoid passing through patient care areas.
- Waste should be transported at pre-scheduled times to prevent mixing with general waste.
- Dedicated, wheeled containers, trolleys, or carts must be used for transporting waste bags or bins to the storage or treatment site.
- These trolleys/carts should be cleaned and disinfected thoroughly, especially after any spillage.

- Containers must be designed to:
- Allow easy loading and unloading
- Secure the waste during movement
- Be free of sharp edges
- Be easy to clean
- Hazardous biomedical waste meant for long-distance transport should be placed in proper containers, clearly labeled for identification and safety.
- Biomedical waste should be transported using dedicated vehicles that are specially designed for this purpose.
- These vehicles must have a fully enclosed body, internally lined with stainless steel or aluminium to ensure a smooth, impervious surface that is easy to clean and disinfect.
- The driver's compartment must be separated from the waste-carrying compartment by a secure bulkhead to ensure safety.
- The waste compartment should be equipped with roof vents to allow proper ventilation during transport.

Need for Biomedical Waste Management
Improper management of biomedical waste poses serious environmental and health hazards to both humans and animals. It can lead to pollution and increased risk of disease transmission.
Healthcare professionals can play a major role in reducing these risks by:
- Properly segregating and disposing of waste in clearly labeled and designated bins.
- Ensuring the facility partners with a reliable and authorized biomedical waste disposal service.

In this plant proper treatment and disposal methods are carried out regarding to waste. Following Steps are:
[a] Collection and Transportation of waste:
The collection of Biomedical Waste in plant involves use of different types of container from various source of biomedical waste. It includes color codding bags and transporting vehicle as per government laws.

[b| Segregation of Waste:
Segregation refers to the basic separation of the different categories of waste generated at source or at a plant. Prevents illegally reuse of certain components of medical waste like used syringes, needles and other plastics are segregated in plant.

[c] Incineration:
Incineration is carried out in plant done at high temperature, which reduces organic and compostable and inorganic compostable matter. Anatomical waste is treated.

[d] Autoclaving:
In plant Autoclaving is done at low heat thermal process and its uses steam for disinfection of waste. Wastes form laboratory cultures, stocks, tubing, catheters and intravenous sets are autoclaved.
Le/Shredder:
In plant Shredder are used to destroy plastic and paper Waste to prevent their reuse. It requires maintenance after specific time interval.

[e]Chemical methods:
In plant chemical methods are used for disinfection of waste such as syringes, needles, drug bottles etc. chemical such as hypochloride is used.

[f] Safety Measures:
In plant during the collection of biomedical waste segregation and treatment processes of biomedical waste have adopted universal precautions and appropriate safety measures are provided while handling the Biomedical Waste, such as mask, goggles, hand gloves, safety shoes etc. to the workers.

Treatment for Biomedical waste management in Kolhapur City:
Incineration -
Incineration of waste converts the biomedical waste into ash, flue gas, and heat. Incinerator has 2 chambers; primary and secondary chamber. Primary chamber has 850 degrees temp. And in secondary chamber 1050 degrees temp.

- Incineration decreases quantity of waste.
- It reduction of pollution.
- Production of heat and power.
- Incinerators have filters for trapping pollutants.
- Saves on transportation of waste.
- Provides better control over noise and odour.
- Prevent the production of methane gas.
- Eliminates harmful germs and chemicals.

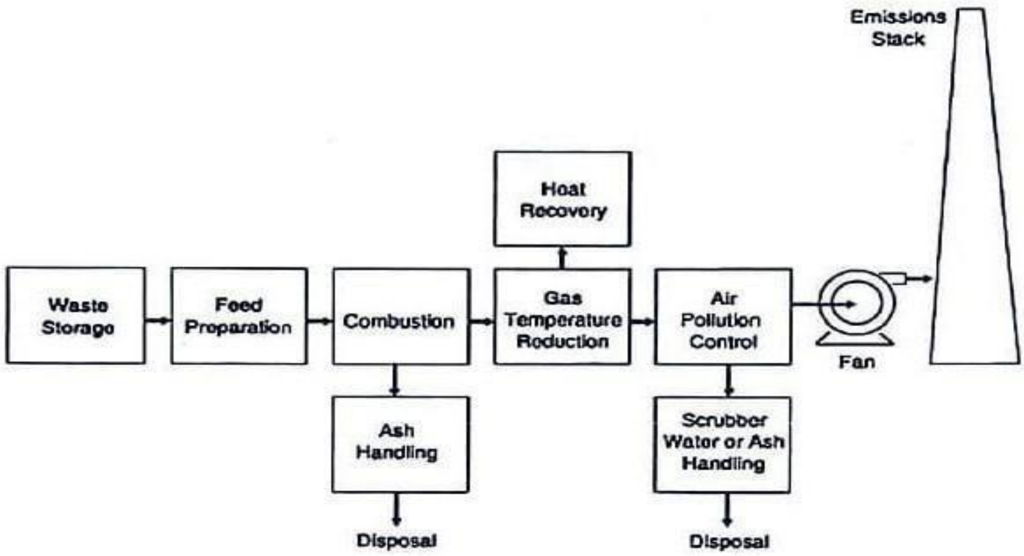

Figure 1 - Incineration Process

Conclusion

Biomedical waste is not just leftover material from hospitals but a hidden danger to people and the environment if it is not handled properly. Every hospital, clinic, lab, or diagnostic center produces this waste every day. Even though the amount may seem small, the harm it can cause is much bigger. Used syringes, blood-stained bandages, and lab samples can spread serious diseases like HIV, Hepatitis B, and Hepatitis C if thrown away carelessly.

In the same way, harmful chemicals, expired medicines, and radioactive waste can pollute soil, water, and air for a long time, damaging nature and risking human and animal health. That is why managing biomedical waste safely is very important—not just for doctors and nurses who handle it directly, but also for protecting the community and keeping the environment safe. The duty of proper waste management is not only on hospitals but also on all healthcare institutions and individuals connected to medical care.

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Noise Pollution and Its Multidimensional Impact on Human Health and Environment

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Abstract
Noise pollution, also known as environmental noise or sound pollution, is the propagation of noise with harmful impact on the activity of human or animal life. The source of outdoor noise worldwide is mainly caused by machines, transport, and propagation systems. Poor urban planning may give rise to noise pollution, as side- by-side industrial and residential buildings can result in noise exposure in the residential areas.

Noise pollution can have significant adverse effects on human health and well-being. Exposure to high levels of noise can lead to a range of health problems, including hearing loss, cardiovascular disease, hypertension, sleep disturbances, and psychological stress. It can also impair cognitive function, reduce productivity, and disrupt communication. The effects of noise pollution are not limited to humans; they also impact wildlife. It can interfere with animal communication, navigation, and reproductive cycles, leading to changes in behavior and even population decline.

Controlling and mitigating noise pollution requires a multi- faceted approach involving government regulations, urban planning, technological innovations, and public awareness campaigns. Governments can implement policies to regulate noise levels from various sources, such as traffic, industries, and construction sites. Urban planners can design cities with noise-sensitive areas, such as residential zones and hospitals, located away from major sources of noise. Technological solutions, such as quieter machinery and noise- canceling materials, can help reduce noise at its source. Finally, public awareness campaigns can educate people about the dangers of noise pollution and encourage them to adopt quieter habits.

In conclusion, noise pollution is a significant environmentalproblem with widespread consequences for both human health and the natural world. Addressing this issue requires a concerted effort from all sectors of society to create a quieter and healthier environment for all.

Noise pollution has emerged as a significant environmental concern in modern urban and industrial societies. It is defined as the excessive or harmful levels of sound in the environment that disrupt human health, well-being, and ecological balance. The primary sources include road traffic, railways, air transport, industrial activities, and urbanization-related construction. Exposure to high levels of noise is associated with adverse health effects such as hearing loss, sleep disturbances, cardiovascular diseases, cognitive impairment in children, and reduced productivity. Beyond human health, noise also affects wildlife by altering communication, breeding patterns, and migration behaviors. The World Health Organization (WHO) has identified environmental noise as a serious public health issue, second only to air pollution in its harmful impact. Effective mitigation strategies include urban planning, stricter regulation of industrial and vehicular noise, use of noise barriers, and public awareness campaigns. Addressing noise pollution requires interdisciplinary approaches that integrate environmental science, public health, and sustainable development policies to safeguard both human and ecological well-being.

Keywords - Environmental Health, Wildlife Disruption, WHO guidelines, Public health, Hearing loss, Public Health, Sleep Disturbance, Stress.

Introduction

Noise pollution, also known as environmental noise or sound pollution, is one of the fastest-growing environmental concerns of modern society. Unlike air, water, or soil pollution, noise does not accumulate in the environment but its effects are immediate, direct, and harmful to both humans and ecosystems. The World Health Organization (WHO) recognizes noise pollution as the second most dangerous environmental threat to human health after air pollution, particularly in urban and industrial regions.

With rapid urbanization, industrialization, and technological advancement, the intensity of noise in cities has reached alarming levels. According to the United Nations Environment Programme (UNEP), more than 100 million people in the European Union are exposed to harmful levels of road traffic noise every year, while millions more worldwide face exposure from industrial and recreational activities. In India, the Central Pollution Control Board (CPCB) regularly identifies metropolitan cities such as Mumbai, Delhi, and Kolkata as "noise hotspots," where sound levels often exceed the permissible limits of 55 dB (daytime) and 45 dB (nighttime) set for residential areas.

Noise is measured in decibels (dB), and while a normal conversation averages around 60 dB, prolonged exposure to sound levels above 85 dB can lead to permanent hearing damage. Sources such as traffic, aircraft, railways, construction, factories, loudspeakers, and household appliances together create a continuous background noise that interferes with health, communication, and overall quality of life. Unlike other pollutants, noise pollution often goes unnoticed until it leads to significant physical, mental, and social consequences.

The issue is not limited to human health. Wildlife is equally vulnerable— studies show that constant anthropogenic (human-made) noise disrupts animal communication, mating calls, migration patterns, and survival strategies. Marine species, in particular, are threatened by noise from ships, oil drilling, and sonar, which interferes with echolocation in whales and dolphins.

Therefore, addressing noise pollution is not just an environmental requirement but also a public health imperative. Understanding its sources, effects, and control measures is crucial for building sustainable, healthier, and quieter communities worldwide.

Major Sources of Noise Pollution

1. Transportation Noise:

Transportation is the largest contributor to environmental noise worldwide.

I. Road Traffic:
- Caused by vehicles (cars, buses, trucks, motorcycles) due to engines, exhaust systems, tire–road interaction, and honking.
- Traffic congestion increases honking and idling noise.
- Studies show road traffic is the most widespread environmental noise source in urban areas (WHO, 2018).

II. Railways:
- Trains generate noise from engines, wheels on tracks, braking, whistles, and vibrations.
- High-speed rail produces aerodynamic noise, while freight trains produce high low-frequency rumbling that travels far.
- Railway noise is linked to annoyance and sleep disturbances near tracks.

III. Air Traffic:
- Aircraft noise comes from take-off, landing, and low-altitude flights.
- Airports are major hotspots; people living nearby are exposed to night and early-morning noise peaks.
- Aircraft noise is strongly linked with hypertension and cognitive impairment in children.

2. Industrial Noise
- Generated from factories, power plants, refineries, mills, and workshops.
- Common sources: heavy machinery, compressors, turbines, fans, boilers, and generators.
- Workers in industries are at risk of occupational noise-induced hearing loss.
- Industrial clusters near residential areas contribute to community noise pollution (OSHA, 2021).

3. Construction and Urban Development
- Noise from construction sites: bulldozers, jackhammers, pile drivers, concrete mixers, drilling, and blasting.
- Road repairs, flyover construction, metro projects, and building demolition add to urban noise.
- Intermittent, high-intensity sounds from construction are especially disruptive.
- According to the U.S. Environmental Protection Agency (EPA), construction activities are among the top urban noise sources (EPA, 2023).

4. Social and Community Noise
- Sources include loudspeakers, music systems, festivals, public gatherings, political rallies, weddings, and sports events.
- In many countries (including India), festivals with firecrackers and amplified sound cause short-term but extreme noise exposure.
- Household sources: televisions, kitchen appliances, vacuum cleaners, washing machines, mixers, and generators.

- Community noise (also called "neighborhood noise") has been recognized by WHO as a health concern (WHO Guidelines, 2018).

5. Military and Defense Activities
   - Noise from weapons testing, aircraft, heavy vehicles, and explosives during training.
   - Sonic booms from military aircraft can affect community's miles away.
   - Prolonged exposure can harm both soldiers and civilians near bases (Basner et al., 2014, The Lancet)

6. Agricultural Activities
   - Use of tractors, harvesters, threshers, water pumps, and other mechanized farm equipment.
   - Though localized, continuous operation contributes to rural noise pollution.
   - Can impact farmers' hearing health if safety measures are ignored (OSHA, 2021).

7. Natural Sources (less common but relevant)
   - Thunderstorms, volcanic eruptions, earthquakes, and strong winds can produce loud natural sounds.
   - Unlike anthropogenic sources, natural noise is usually temporary and less harmful.

However, it can add to ambient noise levels in certain conditions.

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2. Effects of Noise Pollution:

1. Effects on Human Health:

a) Auditory Effects:

- **Noise-Induced Hearing Loss (NIHL):**
  Prolonged exposure to sounds above 85 decibels (dB) can damage the hair cells of the inner ear, leading to permanent hearing loss.

Common among workers in factories, airports, and construction sites.

- Tinnitus:

A persistent ringing or buzzing in the ears caused by prolonged noise exposure.

b) Non-Auditory Effects:

I. Sleep Disturbance:
Even moderate noise at night (e.g., from traffic or aircraft) disrupts sleep cycles.
Leads to daytime drowsiness, fatigue, and poor mental functioning.

WHO recommends night noise levels below 40 dB for healthy sleep (WHO Guidelines, 2018).

II. Cardiovascular Diseases:
Chronic exposure to noise activates the body's stress response, increasing blood pressure, heart rate, and stress hormone levels.

Linked to hypertension, ischemic heart disease, and stroke.
A meta-analysis by The Lancet found strong evidence connecting noise pollution with cardiovascular mortality (Basner et al., 2014).

III. Mental Health Issues:
Constant exposure leads to stress, anxiety, irritability, and annoyance. Chronic annoyance is recognized as a health effect in itself by WHO. Long-term noise exposure may also increase the risk of depression.

IV. Reduced Work Productivity:
Workplace noise reduces concentration, efficiency, and memory retention.
Offices near highways, airports, or construction sites face higher productivity losses.

2. **Effects on Children: Cognitive**

Impairment:
Children exposed to high levels of road or aircraft noise show lower reading comprehension, reduced attention, and poorer memory.
A 2023 meta-analysis confirmed significant negative impacts on learning outcomes (Zhang et al., 2023, Int. J. Environ. Res. Public Health).

Sleep Disturbance:
Disturbed sleep in children affects growth, emotional stability, and immune function.
Emotional and Behavioral Issues:
Noise increases stress and may contribute to hyperactivity and behavioral disorders.

3. Effects on Wildlife and Ecosystems: Birds:
Change the pitch and timing of songs to avoid being masked by traffic or industrial noise. This disrupts mating and communication.

Marine Life:
Ships and sonar systems produce underwater noise that interferes with whales' and dolphins' navigation and communication.
Terrestrial Animals:
Noise reduces feeding efficiency, increases stress, and causes habitat displacement.

4. Effects on Society and Economy Property Values:
Homes near airports, railways, and highways often sell for less due to noise exposure.

Healthcare Costs:
Increased spending on treatment of noise-related diseases such as hypertension, cardiovascular illness, and hearing loss.

Workplace Accidents:
Noisy environments reduce focus, leading to more workplace errors and accidents.

Social Conflict:
Neighborhood disputes often arise from loud music, parties, or construction noise.

5. Environmental Effects
Noise does not accumulate like air or water pollutants, but:

I. It disrupts natural soundscapes in forests, parks, and reserves.
II. Interferes with ecological balance by affecting predator–prey communication.
III. Reduces biodiversity in areas with chronic industrial or transport noise.

Measurement of Noise Pollution:

Noise pollution is quantified mainly in decibels (dB), using logarithmic scales. Different tools and indicators are used to assess intensity, duration, and exposure patterns.

a) Units and Indicators

Decibel (dB): Measurement of sound pressure level (SPL).

dB (A): Weighted scale that mimics human hearing sensitivity (most common).

Equivalent Continuous Sound Level: Average noise level over a period of time.

Lmax and Lmin: Maximum and minimum levels recorded.

Day-Night Average Sound Level: Weighted average noise level with penalties added for night noise.

Percentile Levels (L10, L50, and L90): Indicate noise levels exceeded for a given % of time (important in traffic studies).

b) Instruments:

Sound Level Meter (SLM): Portable device for instantaneous noise measurement.

Noise Dosimeter: Worn by workers to measure cumulative personal noise exposure over time (used in industries).

Integrated Sound Analyzers: Advanced devices for frequency analysis and continuous monitoring.

Noise Mapping Systems: GIS-based tools used by cities to monitor and visualize noise levels (e.g., European Noise Directive requirement).

c) Standards and Guidelines:

WHO: Recommends ≤ 55 dB (day) and ≤ 40 dB (night) for healthy living.

CPCB: (India, 2000 Rules):

- Industrial: 75 dB (day), 70 dB (night)
- Commercial: 65 dB (day), 55 dB (night)
- Residential: 55 dB (day), 45 dB (night)
- Silence Zone (near schools, hospitals): 50 dB (day), 40 dB (night)

Mitigation of Noise Pollution

Mitigation means reducing noise at the source, along the path, and at the receiver's end.

a) At Source
  - Vehicle design improvements: Quieter engines, exhaust mufflers, low noise tires.
  - Industrial noise control: Maintenance of machinery, vibration isolation, Silencers, and acoustic enclosures.
  - Aircraft modifications: Quieter jet engines, optimized flight paths, restrictions on night flights.

b) Along the Path
  - Noise Barriers: Walls, embankments, and transparent shields along highways and railways reduce propagation.
  - Green Belts: Planting trees and shrubs helps absorb and deflect sound.
  - Zoning Laws: Separation of residential areas from industries and highways.

c) At Receiver's End
  - Building Design: Use of soundproof windows, insulated walls, double glazing, and acoustic ceilings.
  - Personal Protection: Use of earplugs and earmuffs for workers in high-noise industries.
  - Community Adaptation: Schools and hospitals located away from high-traffic zones.

Control Measures of Noise Pollution

Control requires policy, regulation, and awareness.

d) Legislative Measures
- International:

WHO guidelines set global benchmarks.
EU Environmental Noise Directive requires noise mapping and action plans.

- India:

Noise Pollution Rules, 2000 under the Environment Protection Act.

Defines permissible limits for industrial, commercial, residential, and Silence zones.

Ban on loudspeakers between 10 PM and 6 AM, except in emergencies.

e) Administrative and Planning Measures

Restricting industrial units near residential areas.

Relocation of bus stands, railway stations, and airports away from populated zones.

Time restrictions on construction activities.

Urban planning with buffer zones and acoustic-friendly infrastructure

f) Technological Measures

Noise monitoring networks in smart cities. Use of quiet road surfaces (porous asphalt).

Adoption of electric vehicles (less engine noise).

Soundproofing public places like hospitals, schools, and libraries.

g) **Public Awareness & Community Measures** Educating people about harmful effects of noise.

Promoting "No Horn Zones" near schools and hospitals.

Encouraging community reportingof excessive noise (festivals,rallies, construction).

Levels of Noise:

Zone	Permissible noise level standards in the Day time (dB)	Permissible noise level standards in the Night (dB)
Industrial Zone	75	70
Commercial Zone	65	55
Residential Zone	55	45
Silent Zone	50	40

Source: (CPCB, Noise Pollution (Regulation and Control) Rules, 2000).

Control and Prevention of Noise Pollution:

- Government Regulations –
  Noise standards by Central Pollution Control Board (CPCB), India and EPA, USA.
  Urban Planning –
  Buffer zones, green belts, and noise barriers near highways. Technology –
  Use of silencers, soundproof materials, and quieter machinery.
- Public Awareness –
  Limiting use of loudspeakers, honking, and fireworks.
- Legislation –
  Many countries have laws to regulate industrial and traffic noise.

Conclusion:

Noise pollution is an invisible but serious environmental problem with far-reaching effects on human health, society, wildlife, and the economy. Prolonged exposure to high noise levels contributes to hearing impairment, sleep disturbance, stress, and cardiovascular diseases, while children suffer from impaired learning and cognitive development. Beyond humans, noise disrupts animal communication, migration, and breeding, threatening biodiversity. Societal impacts include increased conflicts, reduced productivity, and a lower quality of life, while economic costs arise from healthcare expenses, loss of efficiency, and property devaluation.

Effective control of noise pollution requires a combination of strict legislation, urban planning, technological innovations, and public awareness. Mitigation measures such as noise barriers, green belts, soundproofing, and zoning regulations must be enforced alongside continuous monitoring. International and national guidelines, like those from the WHO and CPCB, play a crucial role in reducing noise exposure. Addressing noise pollution not only protects health and ecosystems but also enhances social well-being and sustainable urban development.

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