ISSN: 0973-4929, Vol. 20, No. (1) 2025, Pg. 19-34

Current World Environment

www.cwejournal.org

Sustainable Management of Landfill Sites in India: Addressing Environmental, Health, and Socioeconomic Challenges

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Abstract

India generates over 62 million tonnes of municipal solid waste annually, with nearly 70% mismanaged, posing severe environmental, public health, and socioeconomic challenges. Landfill sites, both formal and informal, are major contributors to methane emissions, groundwater contamination, and biodiversity loss, undermining national climate goals and disproportionately affecting vulnerable populations, particularly informal waste workers. Despite progressive frameworks like the SWM Rules (2016) and initiatives such as SBM-U 2.0, implementation remains fragmented due to limited municipal capacity, weak enforcement, and inadequate stakeholder inclusion. This review critically examines the multidimensional impacts of landfill operations in India, evaluates current policy mechanisms, and assesses emerging technologies such as biomining, bioremediation, and waste-to-energy systems. It proposes a holistic, equity-oriented framework for sustainable landfill governance that integrates environmental, health, and social justice perspectives. Emphasizing decentralization, stakeholder participation, and climate resilience, the study advocates for reform pathways that align landfill management with India's sustainable development and circular economy goals.

Article History

Received: 30 January 2025

Accepted: 22 April 2025

Keywords

Leachate;
Landfill;
Methane Emissions;
Municipal Solid Waste;
Socioeconomic Impacts;
Sustainable Waste Management.

Introduction

Municipal solid waste (MSW) management in India historically depended on landfills until recent rapid urbanization alongside consumption growth caused landfills to become contaminated sites, which was accompanied by health threats and social inequality. The Central Pollution Control Board (CPCB) reported that India produces 62 million tonnes of MSW per year, and scientists project this amount to reach 165 million tonnes by 2030.[1–3] The waste collection system reached 92% efficiency, but scientific waste treatment accounts for only 54% of the waste stream, while more than 2,400 active dumpsites continue accepting mixed waste.[2,3] The sites lack proper engineering and linear construction, which leads to

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Doi: https://dx.doi.org/10.12944/CWE.20.1.3

extensive leakage of leachates as well as hazardous pollutants and methane emissions.[4,5]

India's solid waste management challenges reflect a complex interplay of public disposal behaviors, resource constraints, and administrative limitations. While urban local bodies often face funding and capacity gaps, effective implementation of Solid Waste Management (SWM) norms also depends on active citizen participation and community-level awareness.[6,7] Such practices generate substantial negative effects on the environment. The polluted liquid material that seeps from landfills (leachate) creates contamination of groundwater alongside nearby surface water bodies, which has been noted in both Ghazipur in Delhi and Deonar in the Mumbai region.[8,9] Methane gas emission during waste decomposition beneath landfills drives a substantial portion of India's greenhouse gas emissions together with uncontrolled landfill fires, which discharge toxic materials to cause health problems in nearby human settlements.[5,10,11] The negative economic impacts of poor landfill management disproportionately impact three major groups: people who pick waste without formal protection, residents of low-income areas and individuals from lower caste systems who live near these sites.[12–14] Urban recycling would not be possible without the work of wastepickers, who risk dangerous conditions without any legal protection because they do not receive societal recognition.[15,16]

Different government initiatives have been established to solve this crisis situation. Under the Solid Waste Management Rules (2016), governments required separation at waste sources while establishing categories for waste-pickers and establishing controlled protocols for landfill closures.[2,3,6] Swachh Bharat Mission–Urban (SBM-U), along with its 2.0 iteration, works toward repairing historical garbage sites while aiming to establish urban areas without waste.[3] The plastic and e-waste sector operates under extended producer responsibility (EPR), and the government invests in waste-to-energy (WTE) technologies.[2,17] These frameworks receive uneven implementation throughout India, where the focus mostly exists in urban areas.[18] WTE plants have uncertain economic viability because Indian waste consists mainly of damp contents with minimum calorific value.[19,20] Moreover, informal waste workers remain largely excluded from formal decision-making and infrastructure investments.[21,22] While previous studies have investigated environmental pollution from landfills or assessed individual policy frameworks, few have adopted an integrated lens that spans environmental science, public health, social justice, and urban policy.[5,23] There is also limited analysis of region-specific waste composition differences, despite evidence that rural areas produce mostly organic waste, whereas metros generate larger volumes of plastic, hazardous, and biomedical waste.[16,24] Additionally, very few studies have evaluated landfill resilience to climate change or explored the long-term sustainability of biomining, bioremediation, and circular economy models in the Indian context.[4,17,25] This review seeks to address these gaps by providing a multidimensional analysis of landfill management in India, covering environmental degradation, health burdens, policy failures, and social inequities. It combines peer-reviewed scientific literature, government reports, and global best practices to offer a comprehensive assessment of the challenges and opportunities for sustainable landfill governance. The objectives of this paper are fourfold: (i) to examine the environmental, health, and socioeconomic impacts of landfills across different regions in India; (ii) to evaluate the strengths and weaknesses of existing policy instruments, including SWM Rules, SBM, and EPR; (iii) to highlight regional disparities in landfill practices and infrastructure; and (iv) to propose an inclusive, circular, and climate-resilient framework for landfill reform that aligns with India's sustainable development goals and Paris Agreement commitments.

Methodology

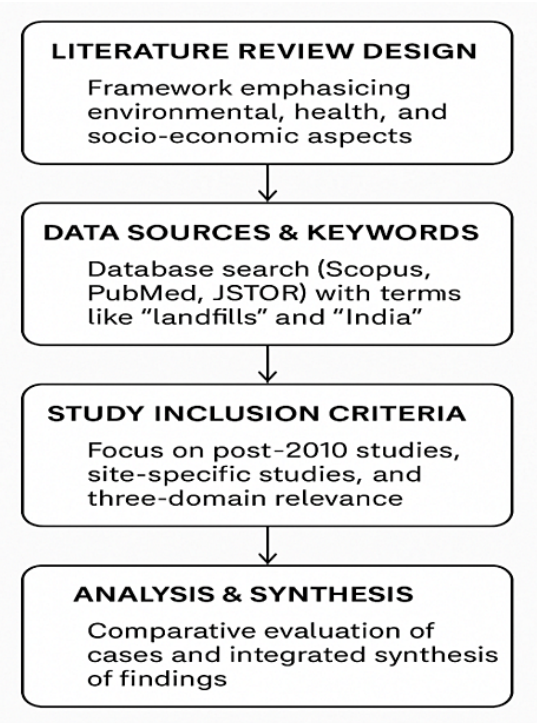
This review adopts a mixed-methods, interdisciplinary approach, combining quantitative data analysis with qualitative policy assessment to evaluate the environmental, health, and socioeconomic impacts of landfill sites in India. The methodology is based on a structured literature review, government reports, and secondary data analysis. Peer-reviewed journal articles, environmental monitoring studies, policy frameworks, and official documents from institutions such as the Central Pollution Control Board (CPCB), the Ministry of Housing and Urban Affairs (MoHUA), and the National Green Tribunal (NGT) were analyzed. Databases such as Scopus, PubMed, and Google Scholar were searched via combinations of the following keywords: "landfill leachate India," "municipal solid waste," "waste-picker health," "SWM

2016 rules," "methane emissions landfill," and "WTE feasibility India." Only sources published between 2008 and 2024 were considered. Studies were included if they provided empirical data or policy evaluations related to landfill sites in India or solid waste management practices. International studies were included only if they offered comparative insights applicable to India. Gray literature (e.g., project reports, state-level SWM reports) was excluded unless it was backed by institutional data (e.g., CPCB, MoHUA). The review is structured into three analytical dimensions: environmental impacts, including leachate pollution, air quality degradation, and biodiversity loss. Public health risks, particularly respiratory diseases, groundwater contamination, and exposure among waste-pickers. Socioeconomic implications include informal labor conditions, land value depreciation, and remediation costs. Quantitative data (e.g., methane emissions, groundwater pollutant levels, and waste volumes) were compiled from CPCB reports and published articles.[2] Qualitative insights were derived from case studies and thematic policy analysis, including evaluations of the SWM Rules (2016), SBM-U 2.0, and extended producer responsibility (EPR) provisions.[2]

Three representative Indian landfill sites—Ghazipur (Delhi), Deonar (Mumbai), and Kodungaiyur (Chennai)—were selected as focal cases on the basis of three criteria: (a) long-term operational history, (b) documented environmental and health impacts, and (c) availability of peer-reviewed data. These sites serve as typologies of large-scale urban landfills in India, reflecting common management failures and regional variation. The combination of statistical review and thematic synthesis allowed the triangulation of findings across technical, public health, and policy dimensions to ensure rigor and relevance.

Solid Waste Management in India: An In-Depth Analysis

Solid waste management (SWM) in India presents a complex and evolving landscape marked by high waste generation, infrastructure disparities, policy implementation gaps, and socioenvironmental consequences. This section provides a detailed analytical overview of India's SWM scenario, integrating government reports, field-level data, and case studies to assess the performance and challenges of collection, treatment, and disposal mechanisms. According to the Central Pollution Control Board,[2] India generates 1,70,339 tons per day (TPD) of MSW, with a collection efficiency of 92%. However, only 54% of this waste is scientifically treated, whereas 24% is landfilled, and the remaining 22% remains untreated or mismanaged.[2,3] Per capita waste generation varies significantly, ranging from 21 g/c/d in Meghalaya to over 500 g/c/d in Delhi, indicating disparities in consumption patterns and waste infrastructure. States such as Chhattisgarh, Lakshadweep, and Andaman & Nicobar have treatment efficiencies above 90%, whereas Arunachal Pradesh and Puducherry lag at less than 15%, revealing regional inequities in waste management systems.[2,3]



Flowchart illustrating the research methodology adopted in this review, integrating literature analysis, case study selection, quantitative and qualitative data evaluation, and thematic synthesis for assessing the environmental, health, and socioeconomic impacts of landfill sites in India

Waste Generation and Collection Trends

India produces approximately 1,70,339 TPD of municipal solid waste, of which approximately 1,56,449 TPD are collected, achieving a high collection efficiency of 92%.[2,3] However, only 54% of this collected waste is treated, highlighting a critical infrastructure and operational gap. Approximately 41,455 TPD are directly landfilled, and 37,373 TPD (22%) remain unaccounted for, indicating systemic leakage in tracking, transport, or treatment.

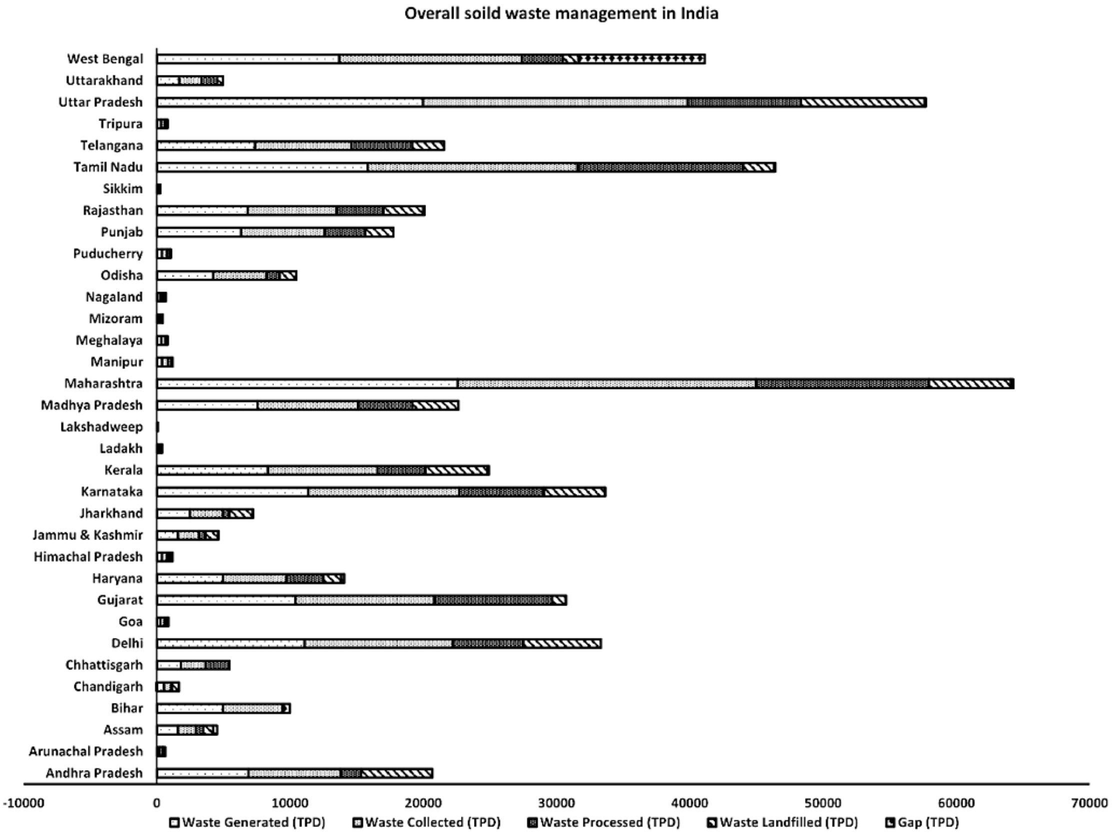


Fig. 1: Overview of solid waste management in India, depicting waste generation, collection, processing, landfilling, and management gaps across states and union territories.[3]

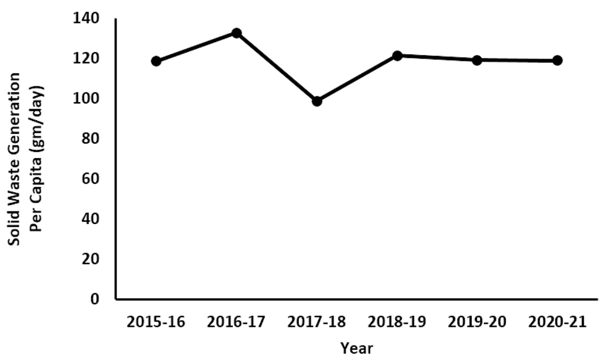


Fig. 2: Per capita solid waste generation rate in India[3]

While some states, such as Chhattisgarh and Goa, have demonstrated over 80% treatment rates through effective decentralization and source segregation, many states underperform due to limited MRFs (material recovery facilities), weak ULB capacity, and low public awareness. Fig. 1 and Fig. 2 illustrate these trends across states.

Waste Processing and Disposal Practices

Despite efforts through SBM-U and policy reforms, India's overall waste treatment remains inconsistent and overly dependent on legacy landfills. While more than one-third of biodegradable waste undergoes composting or vermicomposting, the processing of recyclables and inerts remains limited. Cities such as Indore and Pune have pioneered bio-methanation plants that convert wet waste to 20,000 kg/day bio-CNG, offering replicable low-emission models. However, treatment success is not uniform. Of the 16 states performing above the national average, many still grapple with capacity mismatches during monsoons or festival periods. Moreover, the high moisture content and heterogeneous composition of MSW limit mechanical processing options.

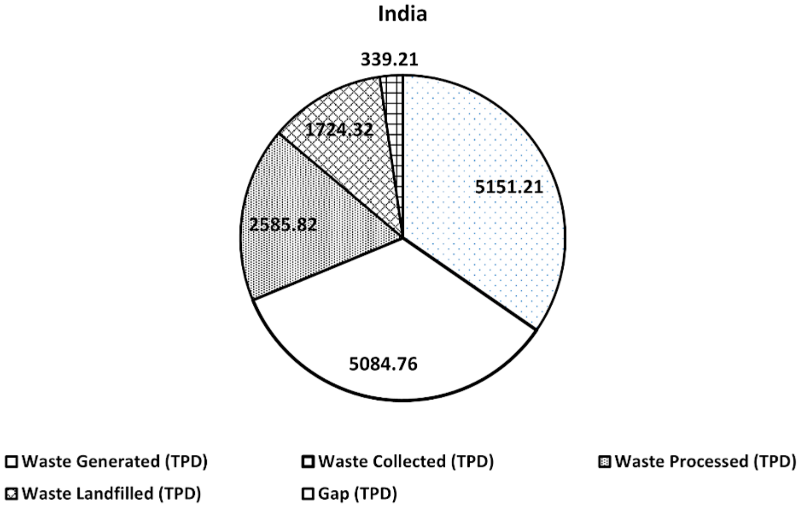


Fig. 3: Distribution of solid waste management components in India, showing waste generation, collection, processing, landfilling, and management gaps(in TPD).[3]

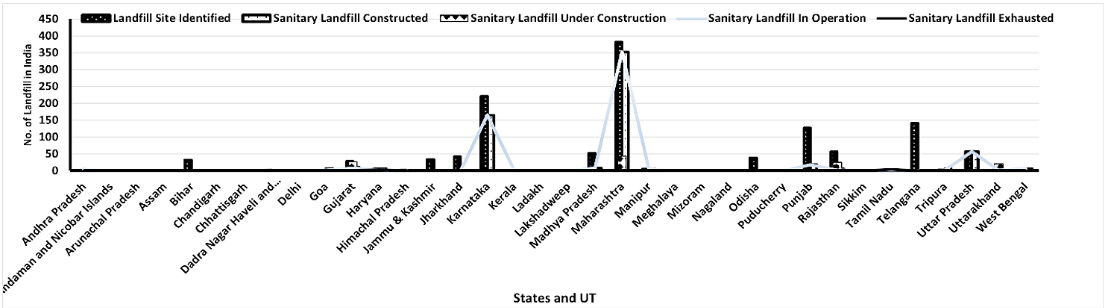


Fig. 4: Status of landfills in India, showing identified sites, constructed landfills, operational status, and exhaustion or capping across states and union territories[3]

Landfills and Dumpsite Realities

India has identified 1,244 landfill sites, of which 645 are active and 10 are fully exhausted. However, over 2,452 active dumpsites remain in use—many functioning without liners, gas collection, or leachate treatment. Landfill dependency, although declining (from 54% in 2017–18 to 21% in 2021–22), remains a significant challenge in Metro Cities such as Delhi and Mumbai. Statewise analysis shows wide variation—for example, Maharashtra has over 350 open dumpsites, whereas Tamil Nadu has reclaimed 69 through bioremediation and biocapping. The Ghazipur, Deonar, and Kodungaiyur landfills, discussed later in section 4, underscore the ecological, health, and sociopolitical burdens imposed by legacy sites.[3,16]

The CPCB report identifies 1,244 landfill sites across India, of which 669 have been constructed and 645 are currently operational. However, the reliance on 2,452 active dumpsites, many of which are non-engineered and lack environmental safeguards, continues to pose serious threats. Maharashtra alone has 352 dumpsites—the highest in the country. Although legacy remediation efforts have begun, including those under SBM-U 2.0, the national capacity to address untreated waste remains constrained by infrastructural and funding limitations.[2,3]

Waste-to-Energy (WTE): Promise or Pitfall?

India currently operates 13 waste-to-energy (WTE) plants generating approximately 127 MW of electricity from 6,800 TPD of non-recyclable waste. While facilities in Delhi (Narela-Bawana), Goa, and Andhra Pradesh show operational promise, several others face public resistance and emission violations.[2,26,27] WTE adoption suffers from fundamental mismatches: India's MSW is typically wet and of low calorific value, rendering incineration inefficient without preprocessing.[19] Moreover, the absence of reliable segregation systems further reduces plant efficiency. As such, WTE risks becoming a techno managerial fix without systemic reform in waste streams.[17]

As of 2022, India had 13 operational WTE plants with a cumulative capacity of 127.072 MW, excluding the additional capacity under development in Uttar Pradesh. These plants process approximately 6,800 TPD of non-recyclable waste, thereby helping reduce landfill dependence. However, issues around feedstock quality and emissions persist, limiting the effectiveness of WTE as a standalone solution.[3,19]

Legal and Institutional Frameworks

The Solid Waste Management Rules, 2016, mandate segregation at the source, decentralized processing, and the inclusion of informal workers in formal waste systems. However, enforcement is inconsistent, particularly in urban local bodies (ULBs) lacking resources or institutional capacity.[2,6] The extended producer responsibility (EPR) mechanism has shown mixed results—while plastic recovery rates have reached over 60% in some states, e-waste and battery waste management remain poorly tracked and inconsistently reported.[2] The inclusion of wastepickers in the formal system has improved recovery rates by up to 30%, yet implementation remains fragmented and inequitable.[14,21,28]

Governmental Flagship Programs

The Swachh Bharat Mission–Urban (SBM-U) has scaled scientific waste processing from 18% in 2014 to 70% in 2022.[3] However, SBM-U 2.0 faces the mammoth task of clearing 16 crore tonnes of legacy waste and reclaiming 15,000 acres of dumpsites by 2026. Complementary schemes such as Galvanizing Organic Bio-Agro Resources Dhan (GOBARdhan) aim to establish 500 waste-to-wealth plants, including 200 bio-CNG units.[2] These efforts reflect strong policy intent but continue to suffer from slow execution, fragmented governance, and limited integration of informal actors.[17,18] As of the 2021–2022 CPCB assessment, the mission facilitated remediation at major sites such as Okhla and Bhalswa in Delhi, with project funding exceeding ₹776 crores. These efforts have led to visible improvements in land reclamation and pollution control at several critical dumpsites.[2,3]

Remediation of Legacy Dumpsites

India's 2,720 dumpsites hold over 16 crore tonnes of unprocessed waste. Projects such as Okhla and Bhalswa (Delhi) and Deonar (Mumbai) have received allocations exceeding ₹776 crores for bioremediation and land reclamation.[2,3] However, many such efforts remain at pilot stages with limited nationwide replication.[17] Construction and demolition (C&D) waste, estimated at 150–500 million tonnes annually, offers a parallel recovery opportunity. Cities such as Bengaluru and Hyderabad have operationalized C&D recovery plants, helping reduce pressure on MSW landfills.[2] However, the national recycling rate remains below 25%, with a target of 70% by 2026.[2]

Regional Waste Profiles and Strategic Implications

Urban centers such as Delhi and Mumbai generate high volumes of nonbiodegradable and hazardous waste, whereas rural and tier-2 towns produce more than 60% organic waste.[16,24] This heterogeneity makes universal solutions ineffective. For example, WTE and RDF facilities thrive in dry-waste-dominant regions but underperform in wetter zones because of their high moisture content and low calorific value.[19] Conversely, biomethanation and decentralized composting are more suitable for smaller towns with higher organic loads.[17] Strategic waste audits must therefore precede project sanctioning to ensure that location-specific solutions are deployed effectively.

Environmental Impacts of Landfills in India

Landfills in India are a major source of environmental degradation, contributing to widespread soil, water, and air pollution. This section presents an integrated analysis of the key environmental issues related to landfill operations across India, with special emphasis on pollution pathways, biodiversity loss, and climate implications.[4,24,29] The findings build on recent case studies to move beyond generalizations by offering site-specific analysis and linking evidence to broader sustainability challenges.[27]

Ground and Surface Water Contamination

The primary environmental crisis from landfills emerges from leachate migration toward underground water resources, which also impacts nearby surface water bodies. Sites such as Ghazipur (Delhi) and Deonar (Mumbai) generate hazardous leachate under inadequate management, containing elevated concentrations of lead, cadmium, arsenic, nitrates, and ammonium.[4,5,8]

In affected zones, nitrate concentrations exceed 60 mg/L, surpassing the WHO limits for drinking water, thus making it unfit for human use.[16,30] At the Kodungaiyur landfill (Chennai), water samples have high COD and BOD levels, confirming organic contamination in local water bodies.[31,32] These pollutants degrade aquatic ecosystems, promote toxic algal blooms, and result in fish mortality, which undermines local fisheries and community livelihoods.[9,33]

Soil Degradation and Agricultural Risks

Areas surrounding landfills exhibit elevated concentrations of toxic metals and organic pollutants, which impair soil microbial communities and reduce soil fertility. Soil analysis near Ghazipur revealed that cadmium and chromium levels exceeded baseline concentrations by up to 4 times.[9,34] This bioaccumulation not only reduces crop productivity but also contaminates the food chain, posing risks to food safety and human health.[32]

Air Pollution and Toxic Emissions

The anaerobic decomposition of organic waste in landfills results in the emission of large volumes of methane (CH_4), a potent greenhouse gas. The Ghazipur landfill alone emits more than 3,000 tonnes/year, equivalent to the annual emissions of 80,000 vehicles.[1,11] Uncontrolled landfill fires emit $PM_{2.5}$, PM_{10}, VOCs, dioxins, and carbon monoxide, contributing to air quality deterioration and respiratory health hazards.[8,10] Studies in Delhi and Mumbai revealed a surge in respiratory cases during fire episodes, confirming the associations among airborne toxins, smog formation, and cardiopulmonary illness.[35]

Biodiversity and Ecosystem Disruption

Landfill expansion into urban peripheries and ecologically sensitive zones leads to habitat destruction and ecosystem fragmentation. The Kodungaiyur landfill has recorded the extinction of ground-dwelling insects and heavy metal accumulation in local flora.[31] At Deonar landfill, contaminated effluents lead to fish mortality, food chain disruption, and economic losses in fisheries.[27,33] These impacts contribute to a decline in biodiversity and ecosystem service loss, a topic often underexamined in the Indian landfill literature but crucial for planning sustainable urban environments.[36]

Landfills and Climate Change Nexus

Landfill-generated methane emissions in India contribute 7–18 million tonnes of CO_2 equivalent annually, via an emission range of 0.33–0.82 Tg/year, significantly impacting the nation's greenhouse gas inventory.[11,37] These emissions undermine India's commitments under the Paris Agreement, exacerbating global warming trends.[5,25] Research models suggest that installing methane capture and flaring systems at key landfill sites could reduce emissions by approximately 50 Mt CO_2 equivalent per year.[5,11] Moreover, climate change-related rainfall variability increases leachate overflow, whereas heatwaves increase spontaneous ignition risks at open dumps.[4] This establishes a self-perpetuating climate–landfill feedback loop, where climate deterioration worsens landfill conditions, which in turn amplifies climate impacts.

Case studies: Ghazipur, Deonar, and Kodungaiyur

- **Ghazipur (Delhi):** Emits more than 3,000 tonnes of methane annually; nitrate levels in borehole water exceed 75 mg/L; and fires frequently release VOCs and dioxins.[1,2,8,11]
- **Deonar (Mumbai):** Leachate COD > 4,000 mg/L; algal blooms and fish kills reported in nearby ponds; community protests have halted expansion proposals.[9,38,39]
- **Kodungaiyur (Chennai):** High levels of SO_2 and NO_x; cadmium and lead above safe thresholds; adverse impacts include stunted crop yields and localized biodiversity collapse.[31,40,41] These case studies reflect broader national failure to implement scientific landfill practices and illustrate how legacy sites destabilize urban ecosystems and public health frameworks.[17,36]

Health Impacts of Landfill Exposure in India

Landfill sites across India pose widespread health hazards, which are now increasingly recognized as a public health concern. This section synthesizes peer-reviewed medical studies and government health assessment reports to evaluate the disease burden among communities living near operational and historical landfill sites.[5,24] The analysis addresses both physical and mental health outcomes, with a particular focus on socially marginalized populations, who face disproportionate exposure and limited healthcare access,[12,35] to include equity considerations in public health risk frameworks.

Respiratory Illness and Airborne Exposure

Residents living within 2–3 kms of large landfill sites face elevated risks of exposure to airborne pollutants, including $PM_{2.5}$, PM_{10}, volatile organic compounds (VOCs), and methane. These emissions originate from three primary sources: waste decomposition, leachate evaporation, and uncontrolled landfill fires.[8,10,11] Scientific investigations near the Ghazipur landfill have shown that asthma and bronchitis cases have increased by 30% relative to those in control areas.[5,35] Similar patterns were recorded in Deonar (Mumbai) and Kodungaiyur (Chennai), where spikes in respiratory hospital admissions correlated with fire incidents and seasonal wind shifts.3[8,41]

Waterborne Diseases and Leachate Exposure

Leachate contamination of groundwater, particularly in urban and peri-urban zones, poses major health hazards. Nitrate levels in borehole samples near Ghazipur and Deonar exceed 75 mg/L, surpassing the WHO limit of 50 mg/L' consistently and contribute to cases of methemoglobinemia or "blue baby syndrome". [8,30] Additionally, total coliforms, fecal coliforms, and enteroviruses have been detected in drinking water supplies, leading to seasonal outbreaks of diarrhea, cholera, and typhoid, especially during monsoon seasons, which intensify leachate migration.[24,42]

Chronic illness and Carcinogenic Exposure

Long-term exposure to heavy metals such as cadmium, lead, and arsenic, as well as carcinogenic compounds such as benzene and dioxins, is associated with various chronic health conditions. Studies conducted in landfill-adjacent neighborhoods have reported an increased prevalence of renal diseases, neurological disorders, and cancers—especially bladder and skin cancers.[43–45] While longitudinal cohort studies remain scarce, cross-sectional data consistently highlight greater health burdens among residents living within 2–5 km of unlined or poorly managed landfill sites.[5,11]

Occupational Hazards for Informal Wastepickers

Informal wastepickers, who constitute the backbone of urban recycling efforts, are disproportionately exposed to hazardous landfill environments. Without personal protective equipment (PPE), many individuals develop chronic respiratory conditions and skin diseases and suffer frequent injuries from handling sharp or contaminated waste.[12,28] Surveys at the Kodungaiyur landfill revealed that 65% of wastepickers reported chronic respiratory symptoms.[41] The combined exposure to toxic fumes, extended working hours, and lack of healthcare access increase vulnerability to tuberculosis and musculoskeletal disorders.[35,46] The absence of formal labor recognition, insurance, and social security further magnifies their risk.[13,21]

Mental health and psychosocial stress

Research into the mental health impacts of landfills remains limited, yet qualitative accounts from affected communities offer compelling insights. Constant exposure to foul odors, waste accumulation, and environmental hazards induces nervousness, stress, and depression among nearby residents.[47,48] In Kodungaiyur and Deonar, residents lacking access to adequate housing reported worsening psychosocial wellbeing, as revealed through expert interviews and field surveys.[12] Elderly people and children experience heightened social isolation, stigma, and restricted physical activity, compounding health vulnerabilities.

Health Burdens in Vulnerable Populations

Children, pregnant women, and elderly individuals face disproportionate health risks due to weaker immune defenses and long-term exposure to toxic elements. High-dose inhalation of dioxins and lead by children is associated with delayed cognitive and motor development, stunted growth, and neurobehavioral impairment.[48,49] Pregnant women living near landfills face increased risks of premature births and low birth weight infants, exacerbated by poor air and water quality.[50]

Summary of Case Findings: Ghazipur, Deonar, and Kodungaiyur

- **Ghazipur (Delhi)** reported a 30% increase in the incidence of respiratory illness, with nitrate (75 mg/L) and arsenic concentrations 10× above the WHO limits in borewell water.[5,8]
- **Deonar (Mumbai):** outpatient visits for typhoid, diarrhea, and skin disorders increase significantly during monsoon seasons because of leachate mobility and contaminated drinking water.[24,38]
- **Kodungaiyur (Chennai):** Blood samples from waste-pickers reveal elevated cadmium and lead levels, which are linked to renal dysfunction and neurological symptoms.[31,41]

These findings highlight the urgent need for targeted public health interventions, policy enforcement, and environmental remediation to mitigate health inequities among landfill-adjacent populations.[17,36]

Socioeconomic Impacts of Landfills in India

The socioeconomic impacts of landfills in India are deeply entrenched, influencing everything from land use and real estate dynamics to informal labor conditions, urban growth constraints, and public health expenditures.[14,28] This section explores these interactions in depth, using regional comparisons, case study findings, and policy critiques. The impacts on marginalized communities, including lower caste populations and informal wastepickers, are examined in relation to spatial inequities and institutional exclusion.[21,51]

Livelihood Impacts on Informal Wastepickers

Informal wastepickers form the backbone of India's recycling economy, recovering up to 25–30% of recyclable material from municipal waste streams.[14,52] Despite their pivotal role, they operate in unregulated, unsafe environments. Daily earnings range from ₹150–₹300, yet workers are routinely exposed to sharp objects, infectious waste, heavy metals, and toxic fumes.[13,28] A field study in Kodungaiyur reported that 65% of wastepickers suffer from chronic respiratory illnesses.[41] Owing to a lack of legal recognition, they are excluded from social protection schemes, which contributes to economic insecurity, occupational injuries, and psychosocial stress.[12,21]

Land Use and Urban Development Constraints

Large landfills displace economically productive land and impede urban development. The Ghazipur landfill in Delhi, covering over 70 acres, blocks infrastructure upgrades and discourages real estate growth.[8,53] Similar spatial pressures exist in Mumbai (Deonar) and Chennai (Kodungaiyur), where landfills abut residential areas and arterial roads. Urban planners struggle to execute smart city initiatives or housing expansions in these zones because of air quality degradation, odor nuisance, and visual blight.[39,54] These conditions foster spatial marginalization and deter infrastructure investment.

Property Evaluation and Community Resistance

Residential property values within a 2–3 km radius of landfills typically drop by 20–40%. In Ghazipur, residents report difficulties selling homes or attracting tenants because of health concerns and environmental stigma.[5,48] Additionally, community resistance to WTE plants and landfill expansion is intensifying due to historic governance failures and a lack of public engagement. To build public trust, municipalities must adopt consultative planning, transparent compensation packages, and environmental grievance redress mechanisms.[39,51]

Economic Cost of Remediation and Environmental Damage

The financial burden of remediating legacy landfills is substantial. Leachate treatment costs range from ₹2,000–₹3,000 per kiloliter, and land reclamation can exceed ₹5–₹10 crores per hectare.[2,19] Healthcare costs in landfill-adjacent communities are 15–25% higher due to elevated chronic illness rates and seasonal disease outbreaks. Clinics near Kodungaiyur and Deonar reported surges in cases during monsoons, which were linked to contaminated air and water.[24,41]

Informal Recycling Sector and Missed Opportunities

Despite its widespread reach, the informal recycling sector in India remains undervalued and marginalized. Unorganized workers are estimated to reclaim up to 60% of recyclable plastics and metals, which could yield an economic value of ₹15,000 crores annually if effectively integrated into formalized waste value chains.[17] The absence of formal recognition leads to inefficiencies, repetition of collection efforts, and exclusion from high-value recycling processes. Integrating this sector through worker cooperatives, material recovery facilities (MRFs), and microenterprises would not only boost economic returns but also dignify labor and reduce occupational hazards.[21,28]

Social Inequities and Environmental Injustices

Exposure to landfills disproportionately affects low-income and marginalized communities, which often live near dumpsites due to the inaccessibility of affordable housing.[51] Women in these areas report lower earnings despite performing equivalent labor, and school dropout rates are higher among children forced to contribute to family income.[13] The overlap of caste, class, and spatial marginalization deepens patterns of environmental injustice, necessitating targeted welfare programs, resettlement support, and inclusive waste governance policies[12,22]

Summary and Forward-Looking Implications

The landfill crisis in India is not merely a challenge of solid waste management—it represents a broader socioeconomic and human rights issue. The consequences—from depreciated property values to the exclusion of labor from formal frameworks—manifest across economic, social, and spatial dimensions.[17,36] The following forward-looking strategies are needed to achieve sustainable landfill reform and equitable waste management:

- Formal recognition of wastepickers as environmental service providers, with legal and financial inclusion.
- Establishment of community-driven land reclamation programs to restore contaminated zones.
- Incorporation of environmental externalities into urban development and land use planning frameworks.
- Adoption of equity-focused SWM strategies, particularly in vulnerable and informal settlements.

Only by confronting these systemic differences can landfill governance transition from a technical fix to a catalyst for social justice and sustainable development.

Policy Framework and Comparative Analysis

The successful implementation of scientific landfill systems requires not only technical capacity and infrastructure but also a robust policy and regulatory framework. Over the past two decades, India has introduced multiple policy instruments—including the Solid Waste Management (SWM) Rules, 2016; Extended Producer Responsibility (EPR) mandates; and urban flagship initiatives such as the Swachh Bharat Mission–Urban 2.0 (SBM-U 2.0) and GOBARdhan.[2,6] However, the execution of these policies is often undermined by financial constraints, interagency coordination gaps, and uneven state-level implementation.[14,18] This section critically assesses India's existing waste policy landscape and compares it with international best practices to inform a more sustainable and equitable transformation framework.

Historical Policy Landscape and Legal Reforms

India’s formal waste governance efforts began with the Municipal Solid Waste (Management and Handling) Rules of 2000, which were later replaced by the more comprehensive SWM Rules of 2016.[2,6] as shown in table 1. These rules mandate segregation at the source, decentralized processing, scientific landfilling, and the inclusion of informal waste workers in the formal system.

Table 1: The initiatives, policies, and financial plans for solid waste management in India

Year	Rules, Policies, Schemes, Financial Plans
1973	Criminal Procedure Code, 1973
1974	The Waste Act (Prevention and Control of Pollution), 1974
1994-95	MSWM Strategy Paper by NEERI
1995	J.S. Bajaj Committee constituted by the Planning Commission
2000	Draft Policy Paper by CPHEEO on MSWM
2005	Recommendations of the Technical Advisory Group on MSWM
2005	12th Finance Commission allocated ₹2,500 Cr for SWM for 2005-2010
2005	JNNURM – 40 MSW projects costing ₹2,186 Cr sanctioned for 65 cities
2006	Strategy and Action Plan – Use of Compost in Cities
2007	11th Five-Year Plan allocated ₹2,210 Cr for MSWM for 2007-2012
2008	National Urban Sanitation Policy (NUSP)
2010	13th Finance Commission set delivery standards for essential services (2010-2015)
2010	National Mission on Environmental Health and Sanitation
2011	Toolkit for Public–Private Partnerships (PPP) in MSWM
2012	Urban Infrastructure Development Scheme for Small and Medium Towns (UIDSSMT)
2014	Swachh Bharat Mission (SBM)
2015	Atal Mission for Rejuvenation and Urban Transformation (AMRUT)
2015	The Smart Cities Programme
2016	Swachh Survekshan introduced by MoHUA
2019	Solid Waste Management (Amendment) Rules, 2019
2020	Program on Energy from Urban, Industrial, Agricultural Wastes/Residues and Municipal Solid Waste
2021	Cabinet approves Swachh Bharat Mission-Urban 2.0 (SBM-U 2.0) with a financial outlay of ₹1,41,600 Cr
2022	High-level meeting by MoHUA to discuss remediation of legacy dumpsites in Delhi under SBM-U 2.0
2023	Union Budget proposes 500 Waste-to-Wealth plants under GOBARdhan scheme with an investment of ₹10,000 Cr
2023	Joint efforts by MoHUA and Maharashtra CM to remediate legacy dumpsites and establish bio-CNG plants in Mumbai
2024	MoHUA releases guidelines for Construction and Demolition (C&D) waste management and highlights achievements of SBM-U

The SWM rules were soon supplemented by other legal instruments, including the following:

- Plastic Waste Management Rules, 2016 – Establishing EPR for plastic producers.
- Bio-Medical Waste Management Rules, 2016 – Regulating hospital and clinic waste handling.
- Construction and demolition (C&D) Waste Rules, 2016 – Mandating on-site waste separation and recovery.

Despite legal clarity, enforcement remains inconsistent, especially in smaller municipalities that lack adequate human resources, monitoring systems, and technological access.[18,55] Overlapping jurisdiction, the absence of data transparency, and weak penalties for noncompliance further erode their effectiveness.

Swachh Bharat Mission and SBM-U 2.0

The Swachh Bharat Mission–Urban (SBM-U) has played a pivotal role in improving waste collection efficiency and urban sanitation infrastructure. From only 18% of MSW processing in 2014, the mission helped increase processing levels to 70% by 2022, indicating a significant operational leap.[2] Under SBM-U 2.0, the Government of India targets the remediation of 16 crore tonnes of legacy waste and the reclamation of over 15,000 acres of dumpsite land through bioremediation and biomining technologies. Notable projects include the Okhla and Bhalswa dumpsite interventions in Delhi, which receive allocations exceeding ₹776 crores.[2]

However, several bottlenecks impede landfill-centric interventions:

- Delayed fund disbursement and bureaucratic overlap between municipal and state agencies.
- There is low adoption of decentralized models such as community-level composting and biomethanation.[18] Marginal involvement of waste-pickers and civil society actors in planning and execution.
- Weak community engagement frameworks, particularly in high-density urban zones.[12,47]

Comparative Policy Analysis: India vs. Global Leaders

Although India's waste governance instruments are structurally aligned with international best practices, implementation weaknesses limit their effectiveness. In contrast, countries such as Japan, the European Union (EU), and the United States (US) demonstrate stronger enforcement, technological integration, and community participation mechanisms[55] as shown in table 2.

Table 2: Comparison of India's SWM Rules (2016) with Global Counterparts

Policy Area	India (SWM Rules 2016)	EU	US	Japan
Waste Segregation	Mandated, weakly enforced	Strict mandates	State-level variance	Nationally mandated
EPR	Present for plastics and e-waste	Mandatory with financial penalties	Limited scope	Robust manufacturer accountability
WTE	Encouraged but inefficient	High-efficiency, low emissions	EPA-regulated	Advanced incineration systems
Landfill Standards	Scientific closure mandated	Pretreatment required	Gas and water monitoring	Limited use, extensive recycling
Public Engagement	Prescribed, rarely practiced	Incentive-based	NGO partnerships	High participation, education-led

India's progress is constrained by limited institutional capacity, poor compliance monitoring, and technology deployment gaps.[6,18] Bridging these gaps requires integrated governance, financial devolution, and localized technology solutions tailored to waste heterogeneity across Indian states.

Implementation Gaps and Systemic Weaknesses

- Institutional fragmentation: Poor coordination between municipalities, SPCBs, and central bodies.
- Financial Constraints: Inadequate funds for infrastructure, monitoring, and WTE viability.
- Enforcement Deficit: Weak penalties, infrequent audits, and political capture of waste contracts.
- Low Public Participation: Minimal awareness and community resistance to siting WTE/ landfills.

Technological and Social Integration Barriers

While advanced technologies such as leachate treatment, methane capture, and biomining offer substantial environmental benefits, their large-scale adoption in India remains constrained by high capital costs, operational complexities, and socioeconomic trade-offs.[19,55] Crucially, these high-tech interventions often exclude informal wastepickers, despite their central role in material recovery and community-level waste sorting.[12] A model example is Pune's SWaCH cooperative, where waste-pickers were formally integrated into material recovery facilities (MRFs) and decentralized composting systems, resulting in higher efficiency, cost savings, and greater social equity.[21] These examples prove that technology and inclusion can be mutually reinforcing and not mutually exclusive.

Recommendations for Policy Reform

To align landfill management with principles of sustainability, justice, and a circular economy, India must pursue a multitiered reform agenda:

- A National Waste Management Authority for unified regulation, policy harmonization, and enforcement should be established.
- Mandate real-time waste audit systems and data reporting across urban local bodies (ULBs), leveraging digital infrastructure.
- Link central funding to ULB performance on segregation, landfill diversion, and informal worker integration.
- Social transition plans offering training, protective gear, and social security for informal waste workers should be implemented.
- Global best practices from the EU and Japan are adopted for extended producer responsibility (EPR), landfill caps, and zero-waste frameworks.

Strengthening India's waste governance system through more coordinated efforts—integrating legal frameworks with community-driven innovations—can significantly enhance the effectiveness of solid waste management. As researchers, it is essential to contribute by recommending technological solutions and knowledge-based approaches that support systemic improvements. Bridging the gap between policy ambition and ground-level reality is essential to uphold public health, advance the circular economy, and ensure environmental justice.[36]

Conclusion

In conclusion, India's landfill management crisis is not merely a technical or environmental issue—it is deeply intertwined with systemic governance failures, social inequities, and public health concerns. While existing regulations like the SWM Rules (2016) and SBM-U 2.0 provide a robust legal framework, the persistent gap between policy and practice has allowed hazardous dumping to continue unchecked. Landfills and open dumpsites, as demonstrated, are significant sources of pollution and health risks, disproportionately affecting marginalized communities. Therefore, addressing these challenges demands more than infrastructure upgrades; it requires a paradigm shift toward inclusive and transparent governance, data-driven decision-making, and the empowerment of informal waste workers. The recommendations provided emphasize the importance of environmental remediation, decentralized waste processing, equitable health access, and institutional reform. Only through a whole-of-society approach that integrates environmental, social, and economic dimensions can India advance toward a circular economy and ensure that landfill governance aligns with its broader commitments to sustainability, justice, and human well-being.

Acknowledgement

The author thanks Kurukshetra University's Institute of Environmental Studies in Haryana for their research facilities. The author also acknowledges the University Grant Commission, which provided funding through a junior research fellowship.

Funding Sources

The author(s) received no financial support for the research, authorship, and/or publication of this article.

Conflict of interest

The authors do not have any conflict of interest.

Data Availability Statement

Data examined throughout this study is provided within the manuscript.

Ethics Statement

This research did not involve human participants, animal subjects, or any material that requires ethical approval.

Informed Consent Statement

This study did not involve human participants, and therefore, informed consent was not required.

Clinical Trial Registration

Not applicable

Permission to Reproduce Material from other Sources

Not Applicable

Author Contributions

The sole author was responsible for the conceptualization, methodology, data collection, analysis, writing, and final approval of the manuscript

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